User Guide
for
Ontario Flow Assessment Tool (OFAT)

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Mapping and Information Resources Branch
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Ministry of Natural Resources and Forestry

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Additional Information

This document contains detailed help for using OFAT to the specifics around input data and models OFAT uses to produce the generated outputs.

Please refer to the original documentation or speak with an expert in this area before using the information for decision-making purposes.

For more information, or if persistent problems occur with the application or the data that OFAT uses, or if anything is omitted from this Help document, please email Spatial Data Infrastructure (SDI), at sdi@ontario.ca.

Executive Summary

Key Words

Ontario Flow Assessment Tool

Abstract

Ontario Flow Assessment Tool version 3 (OFAT) is an online spatially-based application which automates several technical and labour- intensive hydrology tasks. It allows the user to view select hydrology information such as stream flow statistics. OFAT calculates flow quantity estimation values and several intermediate outputs, such as watershed delineation and characterization. These derivatives can be used by a variety of users and applied to many water-related applications.

Using a base map for reference, the OFAT user defines a watershed drainage point on a mapped hydrology feature such as a stream, river, or lake anywhere within the land boundary of Ontario, including Ontario's Far North. The resulting watershed polygon can then be used within OFAT to summarize key watershed characteristics. The watershed boundary and characteristics are used in Flood Flow, Low Flow, and Mean Annual Flow models.

The user can view all spatial and tabular outputs online and download the outputs for further specialized viewing or analysis. A standard Internet browser is required to use OFAT.

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List of Acronyms

CFA: Consolidated Frequency Analysis

DEM: Digital Elevation Model

EPA: Expected Probability Adjustment

FDC: Flow Duration Curve

GIS: Geographic Information Systems

HIF: Flood Prediction Models

HYDAT: Environment Canada's Hydrometric database

IDF: Intensity-Duration-Frequency

LCC: Lambert Conformal Conic

LFA: Low Flow Frequency Analysis

LOF: Low Flow Prediction Models

MAF: Mean Annual Flow Prediction Model

MIRB: Mapping and Information Resources Branch

MNRF: Ontario Ministry of Natural Resources and Forestry

MOEE: Ministry of Environment and Energy

NESI: North East Science and Information

OFAT: Ontario Flow Assessment Tool

OIH: Ontario Integrated Hydrology

OPG: Ontario Power Generation

OPS: Ontario Public Service

RHBN: Reference Hydrometric Basin Network

SDI: Spatial Data Infrastructure

UTM: Universal Transverse Mercator

WRIP: Water Resources Information Program

1.0 Overview of OFAT

1.1 Background

When initially released in 2002, the Ontario Flow Assessment Techniques 1 (OFAT 1), developed by the Ministry of Natural Resources' North East Science and Information (NESI), was a system ahead of its time. OFAT 1 was visionary, providing automated implementation of existing, very labour intensive, manual hydrology calculations (Chang et al. 2002). This system provided users with the potential to estimate flow regimes representing low flows (e.g., 7Q2, 7Q10, 7Q20, etc.), flood flows (e.g., Q2, Q10, Q25, Q100, etc.), mean annual flows, minimum instream flow requirements, and bankfull flows for watersheds in Ontario outside the extent of the far north of the province. This functionality allowed users to compare and explore obtained results across regional models with the confidence of standardized Geographic Information System (GIS) processes and attribute handling.

OFAT 1 was a customized add-on to proprietary GIS software. Updates to newer versions of GIS software necessitated a re-work of OFAT. In 2003, work began on OFAT 2, but was never fully completed. A major innovation with OFAT 2 was the inclusion of a "Daily Flow Toolkit". Using the refined and quality controlled time-series flow data from Environment Canada's Hydrometric (HYDAT) database, this Toolkit contained the functionality to derive 6 daily flow calculations.

The provincial need for "OFAT-like" functionality across Ontario has not diminished over the intervening years, evidenced by regular requests for OFAT and OFAT outputs. In the far north of Ontario, this need was heightened with the initiation of land use planning activities across this zone. These factors led the MNR's Water Resources Information Program (WRIP), with support from the Far North Branch, Integration Branch, and the Land and Resources Cluster, to build OFAT 3.

1.2 Functionality

A central requirement of any spatial hydrology modelling tool is the ability to accurately delineate and characterize watersheds. An objective of the OFAT 3 project was to develop such a tool that was easily and openly accessible for widespread application via the Internet.

Such an application serves the needs of the flow modelling community and can be actively employed to support science and policy groups across the Ontario Public Service (OPS) (and beyond) that require access to authoritative watershed definitions and characteristics. For example, the Ontario's Far North planning area represents 44% of the province and within this zone there is a severe shortage of flow monitoring data. Understanding our water resources in this part of the province requires a heavy reliance on modelled approaches.

At the core of OFAT 1 and 2 was the automated implementation of 18 existing regional hydrologic models and empirical relationships pertaining to flow estimation in Ontario. In recognition that many of these models/equations are now dated and/or rarely used in Ontario, it was decided early in the project that an independent evaluation of regional models/empirical relationships would be conducted by Trent University's Institute of Watershed Science. This evaluation, and consultation with the hydrology community to gauge the applicability/value of the individual models, led to the implementation of five regional hydrology models for OFAT 3.

The hydrology models currently in OFAT are:

- Flood Flow – Index Flood with Expected Probability Adjustment (Moin & Shaw 1985)
- Flood Flow – Primary Multiple Regression Method (Moin & Shaw 1985)
- Low Flow – Graphical Index Method (MOEE, 1995)
- Low Flow – Regression Method (MOEE, 1995)
- Mean Annual Flow – Mean Annual Flow (MNR 2003)

1.3 Use and Limitations of OFAT

The most fundamental function of OFAT is to generate a watershed from a pour point within 90 metres (m) of a watercourse in Ontario. Watersheds can be included in a wide variety of planning and analysis.

Most often streamflow statistics are required in areas where streamflow gauges do not exist. OFAT generates modelled streamflow statistics for any mapped stream reach in Ontario. Depending on the use of the output, field verification may be appropriate.

- Among other applications, baseline flow information is needed to:
- Design hydraulic structures such as culverts, bridges, dams, etc.
- Protect or enhance fish habitat.
- Support an ecosystem approach to land and water management.
- Water use and wastewater permitting analysis.
- Support various academic studies.

Provincial specific application areas of OFAT are listed in Appendix 2.

The generated streamflow statistics from the models assume natural flow conditions within the watershed of interest. Influences that regulate flow in any way, such as dams, or withdrawals, can significantly alter the flow quantity. Also, the flow models require certain ranges of input parameters such as drainage area of the watershed. If parameters fall outside of the range required for the model, such as the drainage area for a very small watershed, results may contain small to large errors. OFAT model outputs include a statement on the status of input parameter ranges for the particular model. OFAT obviously cannot provide tools for all water related applications, which is why all data generated in OFAT can be downloaded for further analysis. The spatial watershed boundary and its associated physical characteristics that are implemented in OFAT provide nearly instant, accurate results that otherwise could be a significant undertaking.

1.4 Data History

As OFAT was first being developed in 2000, base data projects were underway to create the provincial hydrology, elevation and derivative GIS datasets necessary to support spatial hydrology analysis. In the absence of yet established provincial datasets WRIP developed a full suite of required data layers as “one-off” products strictly to support OFAT and OFAT users. While this was a practical response to the data gap, it was not optimal in terms of data quality, data updating, and longer term ability to integrate with other data. Since the initial OFAT development, these required datasets have been produced in Universal Transverse Mercator (UTM) projections in a more rigorously standardized and quality controlled environment (Kenny and Matthews 2005; Kenny et al. 2008; WRIP 2008a, 2008b, 2008c; Zhao et al. in press). These data products are substantially refined and are now openly available to Ontario’s water management community.

As refined and useful as these hydrology and elevation data holdings are, there were still several limitations to using these data uniformly across the province in a modelling environment that might encompass watersheds that span more than half the province. These challenges include:

- The scale of provincial base data and derived data was variable. The base data was 1:10,000 scale in southern Ontario and 1:20,000 scale in northern Ontario.
- The raster hydrology, elevation and derivative data layers were developed in a UTM projection (4 zones) which critically limits spatial watershed representation across UTM zones.
- The data holdings were not Provincial in scope (a usable hydrology base in the far north was absent).

A major undertaking to address these issues has now been completed by producing GIS hydrology, elevation, and hydrology derivative datasets in a seamless, standardized, Lambert Conformal Conic (LCC) projection for the entire province. The base hydrology data in this projection allows users to work in a seamless data environment. To address base data scale differences all developed raster data layers have been created at a uniform 30 metre grid resolution. This seamless LCC data is employed as the backbone of OFAT.

A detailed data description and links to metadata are provided in Section 5.0.

1.5 Website

The OFAT 3 release is a spatial web application. Deployment in a web environment offers numerous advantages over that of a desktop application or GIS extension including:

- Only a web browser is needed to use OFAT. The user doesn't need GIS software.
- Updates and additions to the tools can be implemented without the need of any action from the user group.
- Improved data can be updated on the web server. No need for users to handle large amounts of input data.
- Output data can be downloaded for those that wish to analyze further.
- Metadata is available in the online user guide.

1.6 Future Enhancements

OFAT is a dynamic application and enhancements are regularly in progress. The Spatial Data Infrastructure (SDI) Unit of the Mapping and Information Resources Branch (MIRB) of the MNRF are willing to entertain any partnerships or suggestions that are compatible with the vision of OFAT.

2.0 OFAT Interface

Only an internet browser is required to run OFAT. No GIS software is needed. Upon starting OFAT the user is presented with a full view of Ontario, along with the surrounding provinces and states. The OFAT tools are functional only within the Ontario portion of the map display. Five Tabs are placed horizontally across the screen below the OFAT banner. Each tab has a set of associated tools.

Figure 1: OFAT Interface

Tools associated with the Navigation, Map Layers, Find Information, and Markup and Printing tabs are briefly explained below. More detailed explanations can be found in the Make a Topographic Map user guide. (https://www.sse.gov.on.ca/sites/MNR-PublicDocs/EN/CMID/Make%20A%20Topo%20Map%20Online%20Help%20English.pdf)

Navigation tab: Zoom and pan around the map, and manage bookmarks.

OFAT tab: The OFAT toolset is explained in the next section.

Find Information tab: Search by text, coordinates, address, assessment parcel, or township/lot/ concession, and zoom to location. Measure tools distance or area.

Markup and Printing tab: Various options for scale, file type, and adding text or basic drawings to the map to highlight information on the print out.

Map Layers tab: Turning map layers on and off, or viewing the legends. There are 2 legends. The OFAT legend will be displayed when the Map Layers tab is opened. There

is a toggle button at the bottom of the legend to switch between the OFAT and Base Data legends.

2.1 OFAT Legend descriptions

Diversion: Identifies a location where water is being diverted from the natural flow. This may be a dam that is blocking flow or a location where water is now flowing through.

Waterbody Outlet: Identifies where water is flowing out of a lake or river. This can aid in deciding where to create a pour point for a watershed by identifying the direction of flow.

Dam: Dams have been categorized into 5 ownership classes which are Conservation Authority, Provincial, Federal, Ontario Power Generation (OPG), and Other.

HYDAT Gauge: Identifies Water Survey of Canada HYDAT Streamflow gauges. HYDAT Gauges that belong to the Reference Hydrometric Basin Network (RHBN) will be displayed on the map as a red symbol with "RHBN" after the gauge name. Gauges that are not part of the RHBN will be displayed as a blue symbol.

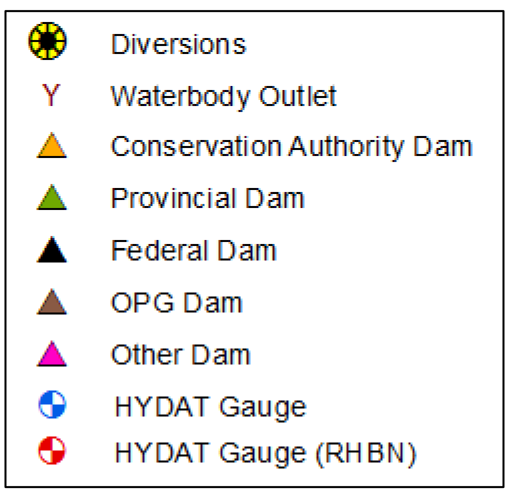

Figure 2: OFAT Map Legend

3.0 OFAT Toolset

This section explains how to use the OFAT tools, and limitations that uses should be aware of.

3.1 Create Watershed

OFAT is capable of delineating a watershed from any user defined point in Ontario that satisfies certain criteria. Generating a watershed is the initial point of the work flow for many of the functions. A watershed is required to perform the subsequent operations in the work flow such as generating watershed characteristics, and executing the hydrology models.

A watershed is created in OFAT by defining a pour point (a point through which all overland flow of the watershed will drain through). A pour point must be created on a mapped hydrology feature (lake or stream), and must exist within the land boundary of Ontario. A point within the Great Lakes, St. Lawrence, Ottawa River, St. Clair, Hudson Bay, James Bay, or similar area will not generate a watershed.

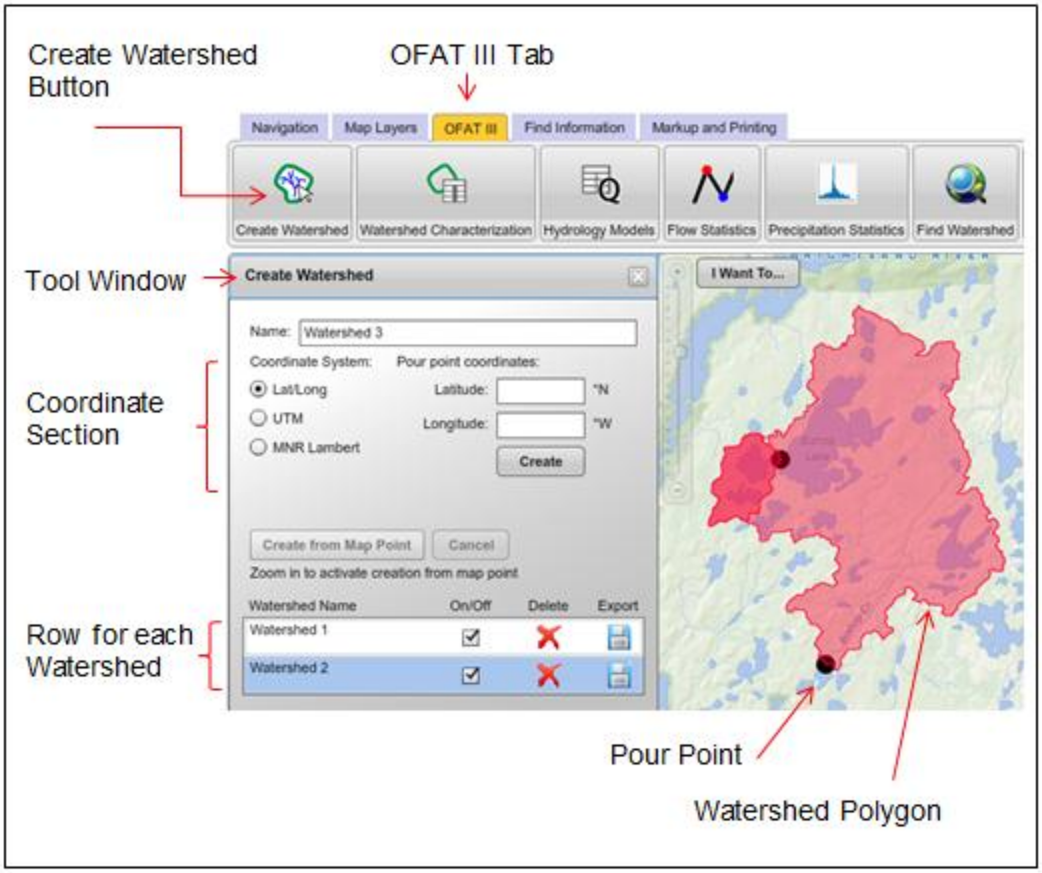

Figure 3: Create Watershed Tool

3.1.1 Steps to run the Create Watershed tool

- Click the OFAT tab.
- Click the Create Watershed button.
- The Create Watershed tool window will appear on the left side of the screen. A default name of Watershed 1 will appear in the text box. This can be changed at this time if desired. The name cannot be changed after the watershed is created.
- Create a pour point with one of two methods:
- Enter the coordinates of the pour point in the text boxes of the coordinate section of the tool window. One of three coordinate systems can be specified. The entered coordinates must be within 90 metres of a mapped hydrology feature. Click the Create button.

- Create a pour point by a mouse click on a mapped hydrology feature. To do this, zoom in until the Create from Map Point button becomes enabled (turns from grey to black). The mouse click must be within 90 metres of a mapped stream or lake. Failure to be within 90 metres of a mapped hydrology feature will return a warning message.
- The generated watershed is added to the bottom row of the tool window and the map display zooms to the watershed extent.
- Multiple watersheds can be created. Each additional watershed will be added to a new row at the bottom of the tool window and to the map.
- Several options are available for each watershed row.
- Click on a row to select (The selected watershed row will be highlighted in blue.) The map display will zoom to the selected watershed.
- The watershed can be turned on and off in the map display by clicking the On/Off checkbox. This is useful when there are multiple overlapping watersheds in the map display.
- The watershed and pour point can be deleted by clicking the Delete icon.
- The watershed and pout point can be downloaded by clicking the Export icon. See section 4.0 Exporting Watershed Information for details on how to export and download.

3.1.2 Notes about Watershed Generation

Each watershed generated in OFAT is independent of any other watershed generated. This allows watersheds to overlap (e.g. nested sub-watersheds).

Caution should be taken when placing a pour point near a stream confluence (where two streams meet and merge into one stream) to achieve desirable results. OFAT uses a 30 metre cell resolution raster Enhanced Flow Direction Grid in generating the watershed. Due to the 30 metre raster resolution, stream confluences within the grid are ‘in the area’ of the mapped stream confluence that is shown on the map. Place the pour point at least 30 metres downstream of the confluence to include the stream junction and all contributing streams in the watershed delineation. Place the pour point at least 30 metres upstream of the confluence to delineate a watershed for only one of the contributing streams.

OFAT can generate a watershed from a pour point within a waterbody (lake or large river). The underlying stream network contains virtual lines that connect flow though

waterbodies. The virtual lines are not visible on the map. The user-defined pour point must fall within 90 metres of a virtual line to generate a watershed. Because the lines are not visible on screen, the pour point may not fall within the tolerance which will result in a warning message. This should only be an issue with very large hydrographic features. The virtual lines will typically be near the centre of the waterbody. A waterbody may contain many virtual lines that represent flow from contributing streams.

Water flow does not start or stop at the borders of Ontario. The input data that OFAT uses to generate watersheds does not always extend beyond the borders of Ontario. Full watersheds will be created along the Quebec border in the area north of the Ottawa River. Watersheds along the Ottawa River and the United States will only represent the Ontario portion.

3.2 Watershed Characterization

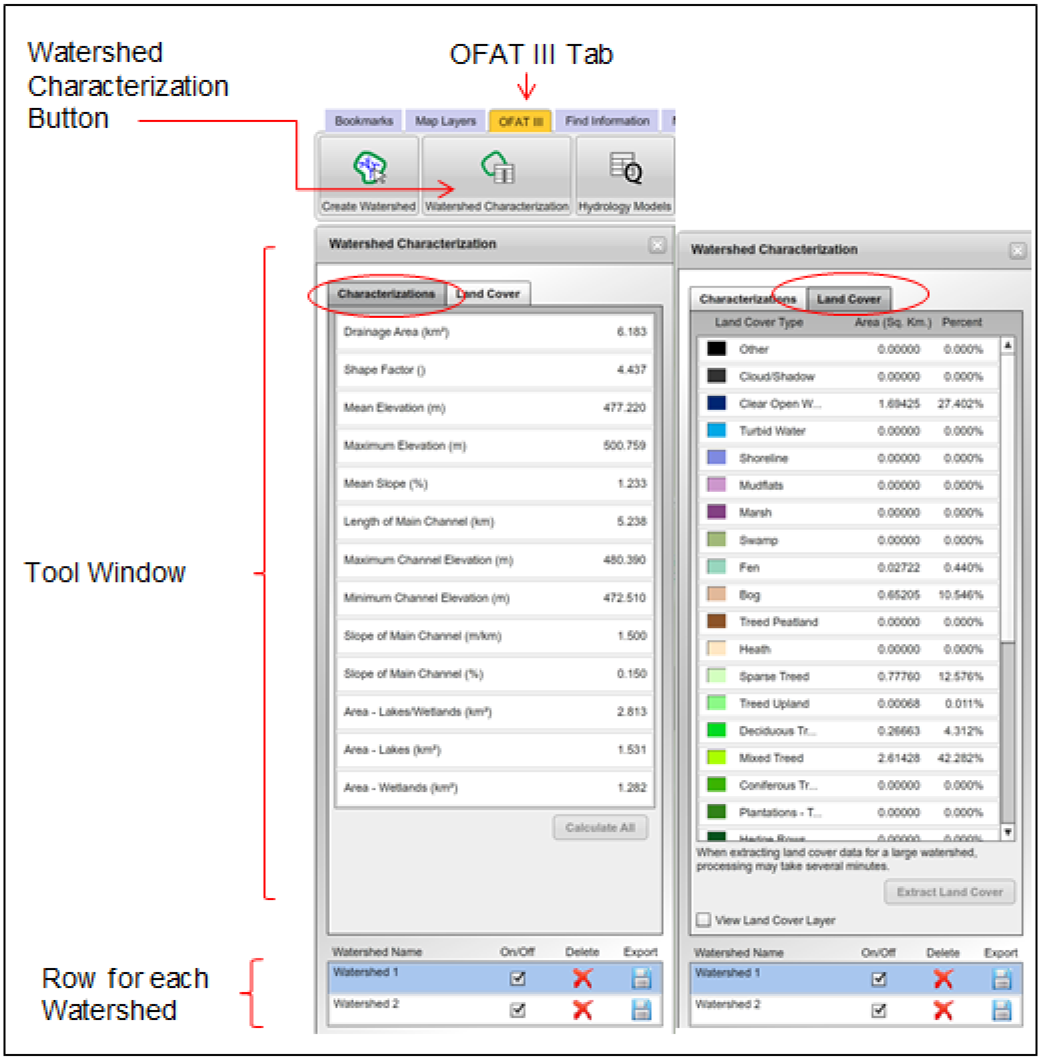

Figure 4: Watershed Characterization Tool

3.2.1 Steps to run the Watershed Characterization tool

- At least one watershed must be generated before using the Watershed Characterization tool.
- Click the OFAT tab.
- Click the Watershed Characterization button to open the tool window. The tool window contains a Characterization tab and a Land Cover tab.

Physiographic Characterization

15 physiographic characterizations can be computed for each generated watershed by:

- Click the Characterization tab in the tool window.
- Click the desired watershed row to calculate in the bottom section of the tool window. (The selected watershed row will be highlighted in blue.)
- Click the Calculate button next to the desired characterization or click the Calculate All button.

The resulting values are displayed next to the characterization name. To calculate and view the characterizations for a different watershed, repeat the steps above for the desired row in the tool window. The values will be updated with the values of the selected (highlighted) watershed row.

For processing efficiency, some characterizations will be calculated at the same time. Clicking Calculate for one characterization may trigger the calculation of others.

Land Cover Classification

30 land cover classes can be extracted and summarized for each generated watershed by:

- Click the Land Cover tab in the tool window.
- Click the desired watershed row to summarize in the bottom section of the tool window. (The selected watershed row will be highlighted in blue.)
- Click the Extract Land Cover.

The resulting values are displayed next to each land cover type summarized by area (km2) and percent coverage within the watershed. To calculate and view the characterizations for a different watershed, repeat the steps above for the desired row in the tool window. The values will be updated with the values of the selected (highlighted) watershed row.

The extraction could take several minutes depending on the size of the watershed.

The land cover can be viewed on the map by selecting the View Land Cover Layer. The viewable layer is for the entire province, not just the watershed.

Export/Download and Metadata

- See Section 4.0 Exporting Watershed Information for details on how to export and download characterization results.
- See section 5.0 Metadata for descriptions of the individual characterizations and data used in calculating the values.

3.3 Flow Prediction: Regional Hydrology Models

OFAT contains a series of regional hydrologic models and empirical relationships that generate water flow information. Flow regimes can be determined for a watershed after the watershed has been generated, and the required characterizations computed.

OFAT currently contains three flow model categories. Each category contains one or more models. See Appendix 1 for a description of each of the models currently in OFAT. For further details about each individual model, please refer to the original literature listed in the references section.

Low Flow Prediction Models (LOF)

This type of model generates low flow predictions such as mQn representing m-day low flow in an n-year return period. For example 7Q20 represents the 7 consecutive day average low flow in a 20 year return period. The low flow prediction models provided in OFAT are:

- Graphical Index Method (MOEE, 1995)
- Regression Method (MOEE, 1995)

Flood Prediction Models (HIF)

This type of model generates flood flows such as Qn representing the flood flow in an n-year return period. For example, Q10 represents the flood flow in a ten year return period. The flood flow prediction models provided in OFAT are:

- Index Flood Method With Expected Probability Adjustment (Moin & Shaw, 1985)
- Primary Multiple Regression Method (Moin & Shaw, 1985)

Mean Annual Flow Prediction Model (MAF)

This type of model generates the mean annual flow for the watershed.

- Isoline Method (MNR 2003)

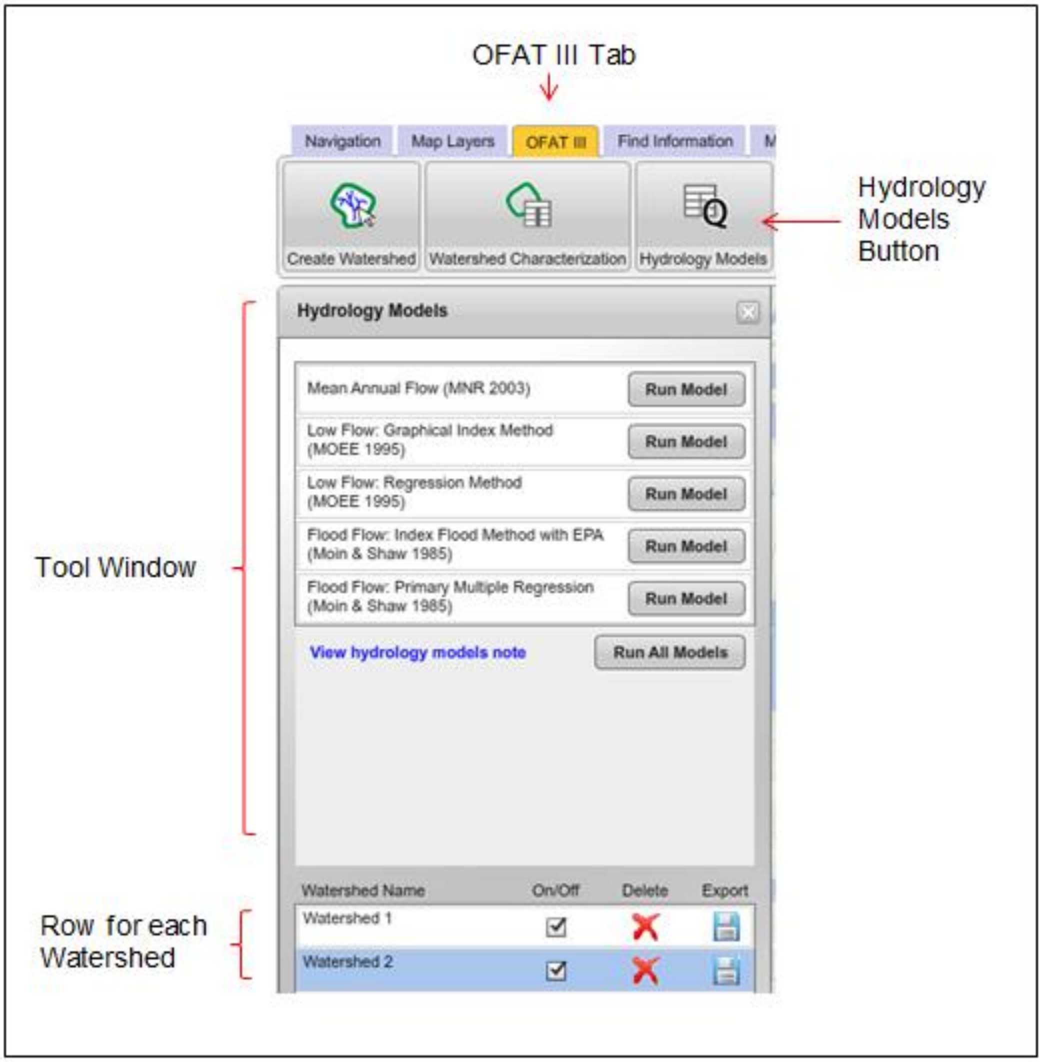

Figure 5: Hydrology Models Tool

3.3.1 Steps to run the Hydrology Models tool

- At least one watershed must be generated before using the Hydrology Models tool.
- Click the OFAT tab.
- Click the Hydrology Models button to open the tool window.

- Click the desired watershed row to calculate in the bottom section of the tool window. (The selected watershed row will be highlighted in blue.)
- Click the Run Model button next to the desired model or click the Run All Models button.

Click the View Flows button to the right of each model name to view the results of each of the executed hydrology models. The values shown are associated with the selected (highlighted in blue) watershed row in the tool window.

Input parameter values for Low Flow and both Flood Flow models are checked with appropriate range values. The results of the input parameter tests are stated at the bottom of the table shown when the View Flows button is clicked. Hover the cursor over the lower row(s) of the results column to see the full statement regarding the parameter test results.

Table 1: Parameter Range Statements for OFAT Regional Hydrology Models.

Model	**Field Name**	**Parameter Range Statements**
Low Flow: Graphical Index	Area Limit	Drainage Area Parameter in/not in range for model.
Low Flow: Regression Method	Range Limit	Parameters DA/LNTH/BFI/MAR are in/outside of the range used to create this model.
Flood Flow: Index with Expected Probability Adjustment (EPA)	Area Limit	Drainage Area Parameter in/not in range for model.
Flood Flow: Primary Multiple Regression	RngQ2Q20, or RngQ50Q100	Parameters DA/SLP/ACLS/BFI/MAR are in/outside of the range used to create this model.

Acronyms used in parameter range statements: DA = Drainage Area, LNTH = Length of Main Channel, SLP = Slope of Main Channel, BFI = Base Flow Index, MAR = Mean Annual Runoff, ACLS = Area of Lakes and Swamps.

3.3.2 Notes about Flow Prediction Models

All model output units are cubic metres per second (cms).

Most models included in OFAT are regional hydrologic models. To estimate flows for a watershed, OFAT uses a model specific region data set (e.g. low flow regions or flood regions) to determine automatically which region or sub-region the watershed is located. Then appropriate sets of equations/relationships are used to calculate the desired flow information.

Each flow model in OFAT has its own limitations. This means that the models included in OFAT should only be used for a watershed within the ranges of the parameters (e.g. drainage area) that were originally used for developing the models. Use of the equations/relationships is not encouraged outside of their parameter ranges. It is strongly suggested that the original model document be referred to, or consult with a water professional, before using generated flow values for any decision making purpose.

Values of -9999 will be inserted for some flow values if the model does not accommodate the specific input parameters for the particular area of the province. These values do not represent an error.

3.4 Flow Statistics

OFAT contains estimates of streamflow (statistics) for select Water Survey of Canada's HYDAT gauges in the Southwestern Hudson Bay, the Nelson River and the Great Lakes-St. Lawrence River watershed systems that lie within the Province of Ontario. The resultant streamflow statistics include:

Mean Annual Flow

Mean annual streamflow (cubic meter per second) is the average streamflow if there are daily streamflow values for the complete year. The calculation is performed on a calendar year basis with historic data from January 1970 (inclusive) onwards. The average value for the number of years of record available is reported.

Flood Flow and Low Flow

A recurrence Interval or Return Period for flood flow is defined as:

An annual maximum event has a return period (or recurrence interval) of T years if its magnitude is equalled or exceeded once, on the average, every T years. The reciprocal of T is the exceedance probability, 1- F, of the event, that is, the probability that the event is equalled or exceeded in any one year (Bedient, 2002).

The probability (P) that an event (F) will occur in any year (T) expressed mathematically as:

$$P(F) = \frac{1}{T}$$

Return Period is the reciprocal of probability and expressed mathematically as:

$$T = \frac{1}{P}$$

The same definition is applied to low flow frequency analysis as well. The major difference from flood frequency is that instead of using the exceedance probability, the non-exceedance probability is used to obtain the probabilities. This is because the return period event is the value that will not be exceeded.

The streamflow statistics include:

- The flood magnitude with recurrence intervals of 1:2, 1:2.33, 1:5, 1:10, 1:20, 1:25, 1:50, 1:100, 1:200 and 1:500 year.
- The n-day drought severity (1,3,7,15 and 30 days) with recurrence intervals of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100 year.
- The 3-day flood magnitude with recurrence intervals of 1:10 year.

To ensure that fish passage is adequate over the desired range of flows, 3Q10 high and 3Q10 low streamflow magnitudes are used as the range. The 3Q10 high was found using the Consolidated Frequency Analysis (CFA) software and the 3Q10 low using Low Flow Frequency Analysis (LFA) program. Water Survey of Canada's HYDAT gauge streamflow data was used for the analysis.

Flow Duration Curve

The Flow Duration Curve represents the relationship between magnitude and frequency of streamflow exceedance. It disregards the sequence of occurrence. It is drawn with streamflow values arranged from highest to lowest (y axis) and percent exceedance (x axis) at each interval. Exceedance Probability (P) is expressed as:

$P = 100*[M/(n+1)]$

- P = the probability that a given streamflow will be equaled or exceeded (% of time)
- M = the ranked position on the listing (dimensionless)
- n = the number of events for period of record (dimensionless)

The Flow Duration Curve is one of the versatile analytical tools used in watershed studies as it has a wide range of applications, including characterizing flow regime, design of hydropower facilities, water budget studies, and comparison of different watersheds.

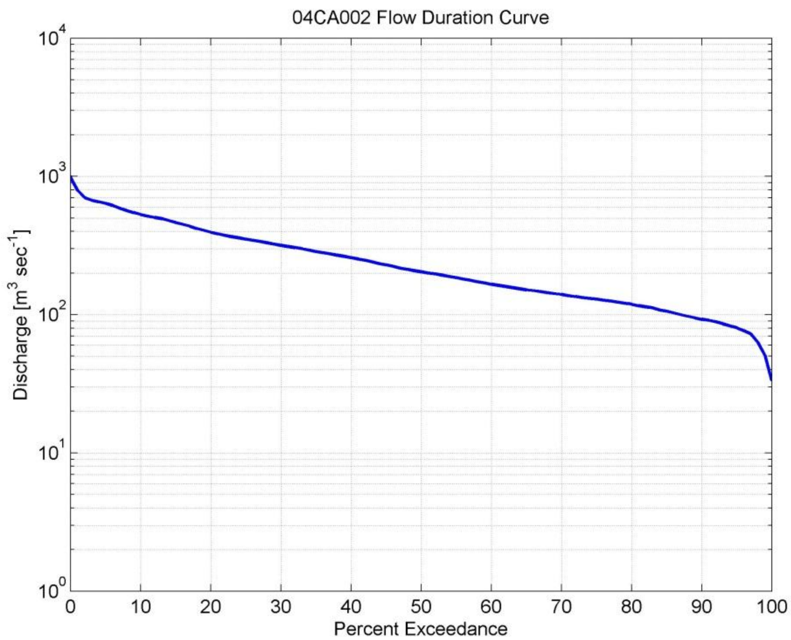

Figure 6: Flow Duration Curve

Historic daily streamflow records from the Water Survey of Canada HYDAT data base from January 1970 onwards were used for generating flow duration curves.

Active gauges with more than 20 years of record, both regulated and natural were selected for their creation. The minimum years of record required to ensure data quality is 20 years. Active gauges with more than 10 years of record are also included for reference. For these gauges it is highly recommended to use the data with caution. Results include the tabular values of annual and monthly Flow Duration Curves and the associated graphical output. The Flow Duration Curves were created by the Period of Record method.

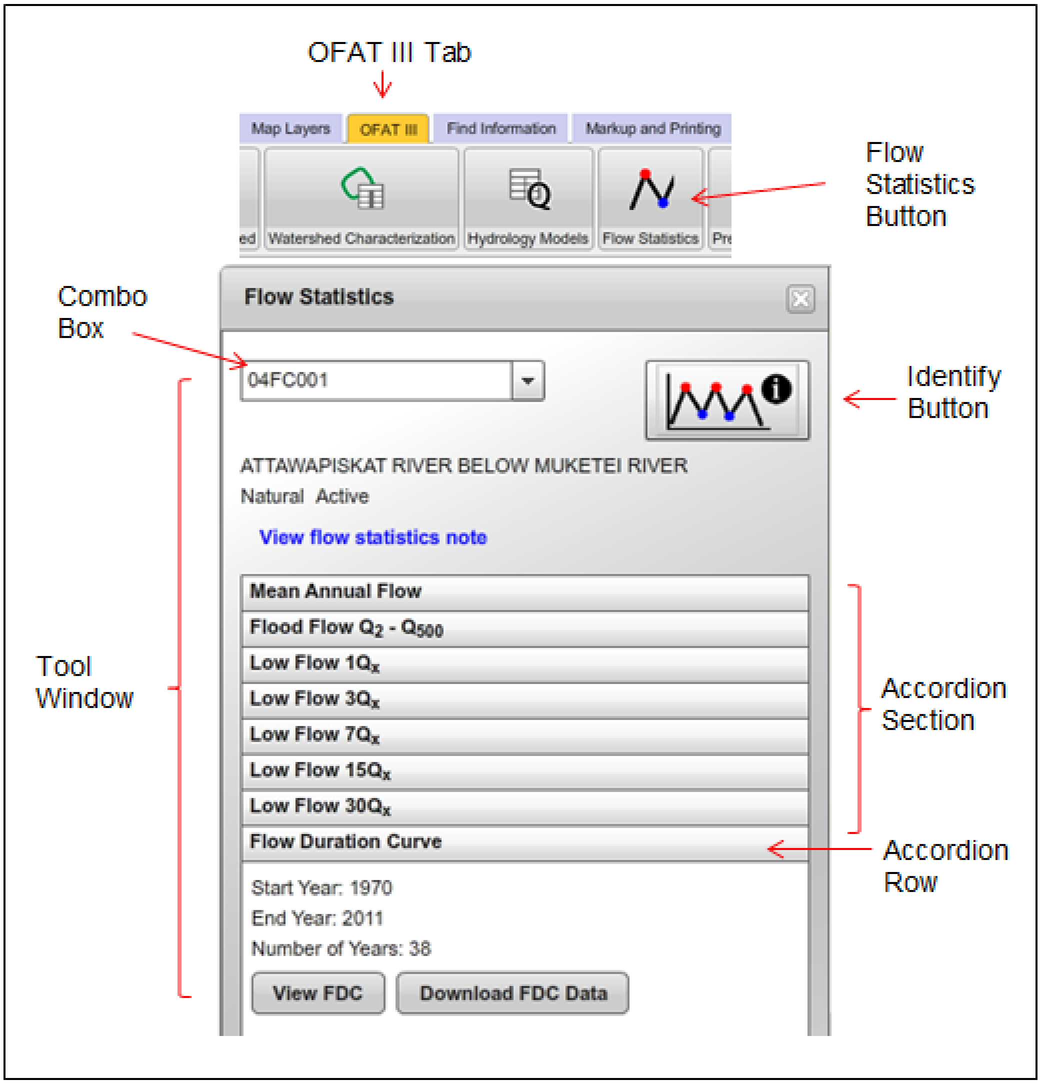

Figure 7: Flow Statistics Tool

3.4.1 Steps to run the Flow Statistics tool

- Click the OFAT tab.
- Click the Flow Statistics button to open the tool window.
- Selecting a gauge to query can be accomplished using one of two methods:
  - Click the combo box drop down arrow at the top left of the Flow Statistics tool window and then select a gauge by its HYDAT ID. It is possible to type in the combo box to narrow the selection.
  - Click on the Flow Statistics identify button at the top right of the tool window and then click on a stream gauge symbol on the map.

As you zoom in on the map the stream gauge name will appear.

The selected gauge will highlight on the map and the flow statistics will be displayed in the accordion section of the tool window. Click on an accordion row to view the flow values. The gauge name, regulation type, and status will be displayed below the combo box.

Click on the Flow Duration Curve accordion row to view a period of record length summary for the selected gauge. Then click the View FDC button to display the graph. Hover the cursor over the curve on the graph to display the value at that point.

You can download a table containing annual and monthly flow values for each percent exceedance for the currently selected gauge station by clicking the Download FDC Data button.

3.5 Find Watershed

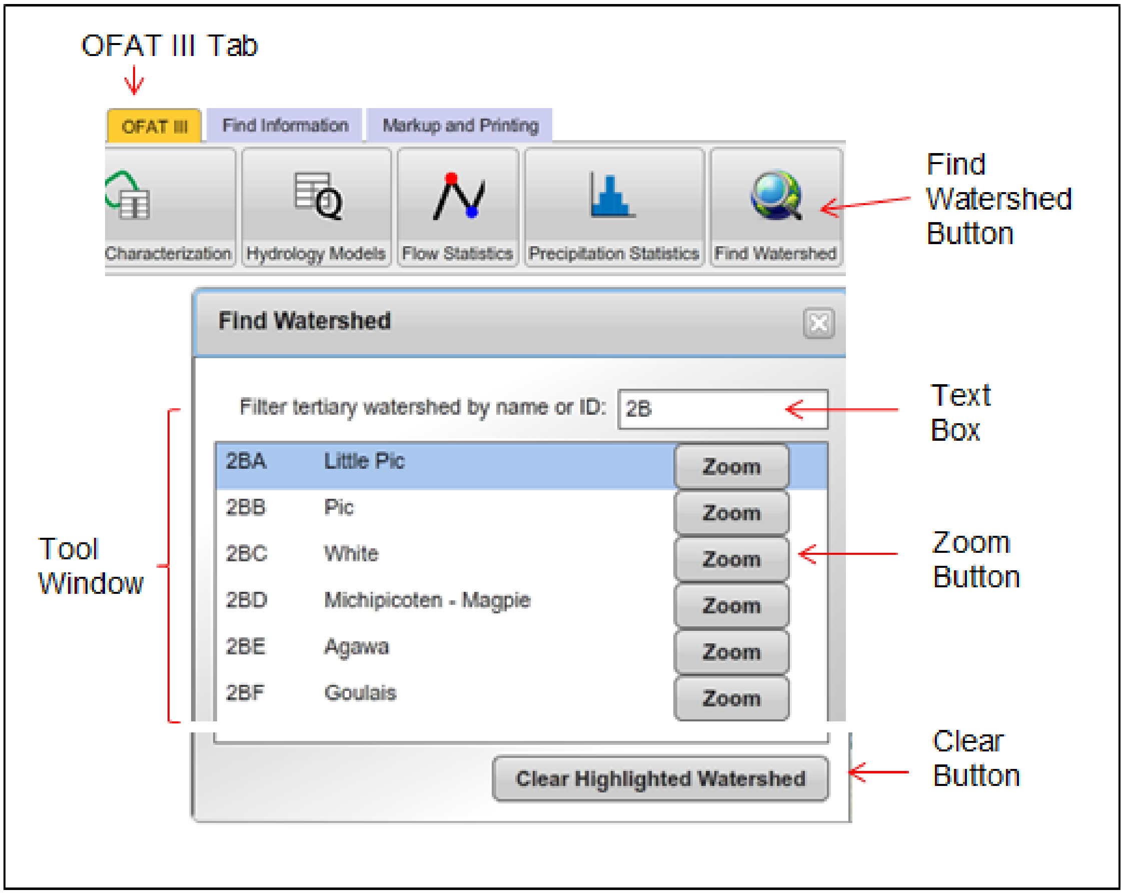

Figure 8: Find Watershed Tool

3.5.1 Steps to run the Find Watershed tool

- Click the OFAT tab.
- Click the Find Watershed button to open the tool window.
- Optionally you can enter part of a watershed name or ID in the text box to filter the list.
- Click the Zoom button beside the desired watershed name or ID.

The map will zoom to and highlight the selected watershed. Click the Clear Highlighted Watershed button to remove the highlight.

4.0 Exporting Watershed Information

All watersheds, watershed characterizations, and hydrology model outputs can be exported (downloaded) from the OFAT website. Lines in the export list that are grey and not selectable have not had the outputs created. Run the characterization and hydrology model tools to produce outputs available for export.

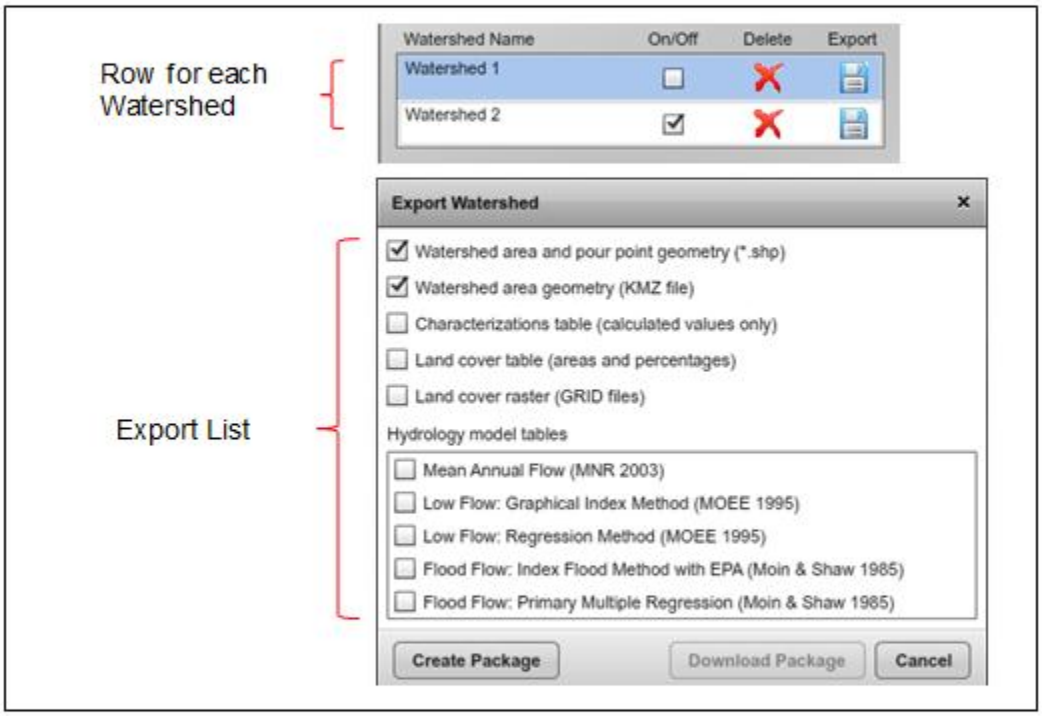

Figure 9: Exporting Watershed Information

4.1 Steps to export watershed information

- Click the Export icon in a watershed row of an OFAT tool to export the data for that particular watershed.
- Check each desired items to include in the export.
- Click Create Package button.
- Click the Download Package button.

4.2 Contents of the Download Package

Extract the contents of the download package compressed zip file. The following list describes the folders and files that can be downloaded.

- kmz (folder)
    - Watershed1.kmz – Google Earth kmz file
- landcoverGRID (folder)
    - info – this folder is required for GIS software
    - landcovr – landcover raster in ESRI GRID format
    - OntarioLandcover.lyr – GIS layer file to be used as a legend file in ArcGIS
- shape (folder)
    - PourPoint shapefile (5 files) – user defined watershed pour point GIS file
    - Watershed shapefile (5 files) – watershed GIS file
- CharacterizationTable.dbf – watershed characterization results table
- IndexEPA.dbf – Moin & Shaw Flood Flow Index with EPA results table
- landcovertable.dbf – summary by area of the land cover within the watershed table
- MAF.dbf – Mean Annual Flow values table
- MOEGI.dbf – MOE Low Flow Graphical Index results table
- MOERegression.dbf – MOE Low Flow Regression results table
- MoinShawRegression.dbf – Moin & Shaw Flood Flow Primary Multiple Regression results table

4.3 Field Descriptions for Exported Tables

Most tables will contain the OFATID attribute which is automatically generated when the user defines a pour point. The ID is carried through to the watershed, characterizations, and hydrology model outputs. The OFATID can be used to organize or link tables and geometries. The following tables contain field names and descriptions for each of the OFAT output tables.

Table 2: Descriptions of pour point fields in PourPoint.dbf.

Field Name	Description
Shape	Geometry of the GIS file. The value will be Point.
OFATID	Auto-generated OFAT ID
WTertiary	Tertiary watershed identifier where the pour point is located
Latitude	Latitude in decimal degrees (NAD 83)
Longitude	Longitude in decimal degrees (NAD 83)
X_LCC	X coordinate in Lambert Conformal Conic (NAD 83)

Field Name	Description
Y_LCC	Y coordinate in Lambert Conformal Conic (NAD 83)

Table 3: Descriptions of watershed polygon fields in Watershed.dbf.

Field Name	Description
Shape	Geometry of the GIS file. The value will be Polygon.
OFATID	Auto-generated OFAT ID

Table 4: Descriptions of characterization fields in CharacterizationTable.dbf.

Field Name	Description
OFATID	Auto-generated OFAT ID
AreaKm	Area of the watershed in square kilometres
ShapFactr	Square of the length of the main channel divided by the drainage area
MeanElevM	Average elevation value of the DEM within the delineated watershed
MaxElevM	Maximum elevation value of the DEM within the delineated watershed
MeanSlpPc	Average slope of the watershed calculated using the slope grid.
LeOMChKm	Length of the main channel (or longest flow path) in kilometres
MaxChElvM	Maximum channel elevation in metres (at the most upstream point of the flow path)
MinChElvM	Minimum channel elevation in metres (at the pour point)
ChSlp_M_Km	Channel slope in metres/kilometre (most upstream point of flow path to the pour point)
ChSlp_Pcnt	Channel slope in percent (most upstream point of flow path to the pour point)
WatrAreaKm	Area covered by Lakes, Rivers, and Wetlands within the watershed in square kilometres
OpWAreaKm	Area in the watershed covered by open rivers and lakes
WetlAreaKm	Area in the watershed covered by wetlands
MeanTemp	Annual Mean Temperature
AnnPrecipt	Annual Precipitation

Table 5: Descriptions of flood flow fields in IndexEPA.dbf.

Field Name	Description
OFATID	Auto-generated OFAT ID
Model	Name of the model
Units	Units
AreaLimit	Result of the model input parameter (watershed area) range test

Table 6: Descriptions of landcover fields in Landcovertable.dbf.

Field Name	Description
Value	Grid cell value
Area	Area of the land cover classification within the watershed in m2
Percentage	Percentage of area of the land cover classification within the watershed
Class_Name	Land cover classification

Table 7: Descriptions of mean annual flow fields in MAF.dbf.

Field Name	Description
OFATID	Auto-generated OFAT ID
Model	Name of the model
Units	Units
MAF	Mean annual flow quantity estimation

Table 8: Descriptions of graphical index method fields in MOEGI.dbf.

Field Name	Description
OFATID	Auto-generated OFAT ID
Model	Name of the model
Units	Units
AreaLimit	Result of the model input parameter (watershed area) range test
LF_(x)Q(y)	Low Flow Quantity averaged over (x) days for a specific return period (y)

Table 9: Descriptions of low flow regression method fields in MOERegression.dbf.

Field Name	Description
OFATID	Auto-generated OFAT ID
Model	Name of the model
Units	Units
RangeLimit	Result of the input parameters range test
LF_(x)Q(y)	Low Flow Quantity averaged over (x) days for a specific return period (y)

Table 10: Descriptions of flood flow regression fields in MoinShawRegression.dbf.

Field Name	Description
OFATID	Auto-generated OFAT ID
Model	Name of the model
Units	Units
RngQ2Q20	Result of the model input parameters range test for the flow estimates between Q2 and Q20
RngQ50Q100	Result of the model input parameters range test for the flow estimates between Q50 and Q100
FF_Q(x)	Flood Flow Quantity for specific return period (x)

4.4 Viewing Options for Exported Files

The following table contains suggested viewing options for the various export package file types.

Table 11: Viewing options for export file types.

File Type	Viewing Options and Notes
.kmz	Open the .kmz file from Windows explorer to view in Google Earth. Must have Google Earth installed on computer.
.shp	Shapefiles can be viewed in many GIS packages. ArcGIS explorer is free GIS viewer that can load shapefiles. Do not alter the associated files that have the same name with different extensions (.dbf, .prj, .shx) to prevent corrupting the GIS file collection.
.dbf	DataBase File can be opened by database, GIS, or spreadsheet software.

File Type	Viewing Options and Notes
GRID	ESRI GRID's are raster files that are opened by GIS software. The Land Cover is extracted in OFAT without the generation of pyramids. Pyramids can be generated for the Land Cover Grid with ArcCatalog for faster viewing in ArcMap.
.lyr	An ESRI Layer file used to color code the Land Cover Raster for map display. Add the layer file into ArcMap and set the data source as the land cover GRID.

5.0 Metadata

This section contains the metadata for the datasets used in OFAT analysis operations. Where possible, metadata links, and document references are provided rather than duplicating published material in this guide.

The OFAT base map is made up of a variety of data from the Ontario Land Information (LIO) Data Warehouse and is not discussed in this document.

For more information about LIO data visit Land Information Ontario's webpage. (http://www.ontario.ca/page/land-information-ontario)

5.1 Ontario Integrated Hydrology Data

The Ontario Integrated Hydrology (OIH) data is a collection of related elevation and mapped water features that are used in combination for generating watersheds and to support hydrology applications.

Because the amount of data for the province is so large, the OIH has been subdivided into 9 separate packages. Each package covers a different part of the province and the data in each package can be updated independent of the others.

View the OIH metadata record on the Ontario Metadata Management Tool. (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=5383ed26-4a12-4026-b624-65c2e431c861)

The OIH metadata record contains transfer (download) options for:

- Packages Map and Watersheds Table. Map illustrating the 9 data packages as well as a table listing the watersheds in each package.
- Package Index Shapefile.
- OIH Data Technical Specifications. Provides a detailed description of OIH data including creation, specifications, uses, limitations, considerations, etc.
- 9 separate data packages

5.2 Data Used in Watershed Delineation

The OIH Stream Geometric Network and Enhanced Flow Direction grid are used for watershed delineation in OFAT.

5.3 Data Used in Watershed Characterization

Watershed Shape Factor: square of the length of the main channel divided by the drainage area.

Watershed Mean Elevation: average of the OIH Digital Elevation Model (DEM) values within the watershed.

Watershed Maximum Elevation: maximum OIH DEM value within the watershed.

Watershed Mean Slope: average Slope Percent grid value within the watershed. The slope percent grid was created with ESRI's Spatial Analyst Slope function on the OIH DEM.

Length of Main Channel: Upstream Flow Length grid value at the pour point. The Upstream Flow Length grid was created with ESRI's Spatial Analyst Flow Length function on the OIH Enhanced Flow Direction (EFD) grid.

Maximum Channel Elevation: OIH DEM elevation value at the most upstream point along the main flow path.

Minimum Channel Elevation: OIH DEM elevation value at the pour point.

Slope of the Main Channel (m/km): Rise divided by run. The difference in the OIH DEM elevation values at the pour point and the most upstream point along the main flow path determine the rise. The Upstream Flow Length as determined in Length of the Main Channel is the run.

Slope of the Main Channel (%): The slope of the main channel (m/km) divided by 1,000 metres to get common units and then multiplied by 100 for percent.

Area of Lakes and Wetlands: Area of lakes and rivers, and wetlands within the watershed.

The Ontario Hydro Network (OHN) – Waterbody data was the source for lakes and rivers.
(https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=3ebaf6b2-6dd6-4ebb-a6bb-4fc778426709)

The Wetland data from the LIO Warehouse was the source for wetland.
(https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=04e466a9-7731-438c-a37a-38fde98202b7)

Both datasets were converted from vector polygons to 30 metre cell rasters. The two rasters were then merged into a single integer raster. In areas where the two original datasets overlapped the lakes and major rivers took precedence over wetland.

Annual Mean Temperature: The data source was Environment Canada historic normal data from 1981 – 2010 in an 8.2 kilometre cell resolution raster. The median of the cell values is reported if 20 or more cells fall within the watershed. The mean of the cell values is reported if less than 20 cells fall within the watershed.
(http://climate.weather.gc.ca/climate_normals/normals_documentation_e.html?docID=1981)

Annual Precipitation: (See description for Annual Mean Temperature)

5.4 Data Used in Watershed Land Cover Summary

The Ontario Land Cover Compilation serves as a consistent land cover map for the entire province to meet regional - to - landscape level analysis (1:50,000 – 1:100,000). This product is comprised of three separate land cover databases, each with separate class structures and which have been rationalized into a single classification.

The Ontario Land Cover Compilation combines the Provincial Land Cover Database, Far North Land Cover and the Southern Ontario Land Resource Information System. Each of these separate land cover databases were resampled to a common pixel

spacing (15 metres), re-projected to a common projection (NAD83 Lambert Conformal Conic) and reclassified into a common class structure.

Data Specification documentation is available for download from the metadata record. (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=46be851e-efc3-4511-bf45-7ac5eb8fd459)

5.5 Data Used in Hydrology Models

Hydrology models in OFAT use information as required from derived watershed characteristics. There are additional data layers required for the regression models. Additional data include:

Mean Annual Runoff: The OFAT Mean Annual Runoff Surface is a 1 kilometre resolution raster data set that represents the mean annual runoff in millimetres at a particular location. This grid was created by North East Science and Information Branch of MNR. The source data to create the grid was taken from Moin and Shaw "Regional Flood Frequency Analysis for Ontario Streams" 1985. Hard copy maps were digitized to create a mean annual runoff contour dataset, which were then interpolated into a surface using TOPOGID. This data is stored in MNRF Lambert Conformal Conic Projection. SDI is not the custodian of this data set.

Base Flow Index: The OFAT Base Flow Index Surface is a 1 kilometre resolution raster data set that represents the portion of flow in a stream derived from soil moisture or groundwater (baseflow). The grid value in any one location represents the ratio of base flow to total flow volume (dimensionless). This grid was created by North East Science and Information Section of MNR. The source data to create the grid was taken from Moin and Shaw "Regional Flood Frequency Analysis for Ontario Streams" 1985. Tabular data from this study was used to create point values which were then interpolated into a continuous surface raster using TOPOGRID. The grid does not cover the entire province. This data is stored in MNRF Lambert Conformal Conic Projection. SDI is not the custodian of this data set.

5.6 Data Used in Streamflow Statistics

The data product (geodatabase) and accompanying technical document are available through the following links:

Flood Flow and Low Flow Statistics: For the Southwestern Hudson Bay and Nelson River Watershed Systems, February 2013. (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=1bcabfe3-47ed-461b-ac00-653c365b53f2)

Baseline Hydrology: For the Southwestern Hudson Bay and Nelson River Watershed Systems, March 2014. (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=b6bb27d4-1a28-4ce1-8195-1caa0b2cced2)

Flood Flow Statistics: For the Great Lakes-St. Lawrence Watershed Systems, November 2014. (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=bf69cb35-ec1f-472d-89f7-4084f94e4472)

6.0 References

This help document contains some content from the original Users Manual for Ontario Flow Assessment Techniques (OFAT) where applicable.

Chang, C., F. Ashenhurst, S. Damaia, and W. Mann (2002). “Ontario Flow Assessment Techniques (OFAT)”, Hydraulic Information Management, Editors, Brebbia, C.A., and W.R. Blain, WIT Press, Ashurst, Southampton, U.K., pp. 421-431.

Kenny, F.M., Matthews, B., 2005. A methodology for aligning raster flow direction data with photogrammetrically mapped hydrology. Computers & Geoscience 31(6), 768-779.

Kenny, F.M, Matthews, B., and Todd K. 2008. Routing Overland Flow through Sinks and Flats in Interpolated Raster Terrain Surfaces. Computers & Geoscience. 34 (2008), pp. 1417-1430 DOI information: 10.1016/j. cageo.2008.02.019.

MOEE (1995). “Regionalization of Low Flow Characteristics” for various regions in Ontario, Ministry of Environment and Energy (MOEE), Ontario, Canada.

Moin, S. and M. Shaw (1985). “Canada/Ontario Flood Damage Reduction Program - Regional Flood Frequency Analysis for Ontario Streams”, Volume 1, 2, and 3, Environment Canada, Ontario, Canada.

WRIP Technical Release 2012. Ontario Integrated Hydrology Data: Elevation and Mapped Water Features for Provincial Scale Hydrology Applications.

Zhao, J., Todd, K., Hogg, A., and Kenny, F. 2008 Improving Ontario’s Provincial Digital Elevation Model. Internal Report, Water Resources Information Program, Ministry of Natural Resources 90p.

Appendix 1: Regional Hydrological Models

Introduction

Frequency analysis is conducted for gathering inference about streamflow. To measure streamflow, hydrometric gauging stations are installed. These stations are installed along the stream reach. But, not all the locations of a stream reach are gauged. Estimates will be biased if flows are pro-rated with the nearby gauge stations, beyond +/- 25% drainage area. Hence, in order to estimate the high/low flow (n-year return level) values at any location of a stream reach, regional hydrologic models have been developed. The regional hydrologic models usually use stochastic modelling techniques. The commonly used stochastic modelling techniques are regression, transfer functions, neural networks and system identification. Mathematical and statistical theories and concepts are used to estimate the parameters. Among the above methodologies, the regression models namely the Index Method and the Multiple Regression Method are widely used in hydrology. These models resolve the problem by "trading space for time" (Hosking and Wallis, 1997). The underlying principle is to transpose the historic streamflow records of the region to the location of interest. This is achieved by building models that combine streamflow at known locations with the corresponding physio-meteriological factors. The above mentioned two methods are also recommended by WMO (1994) for frequency studies. Amongst the two, the Index method is the simplest method.

The steps involved in developing regional models are:

- Develop a Single Station Frequency Curve
- Delineate Homogenous Regions
- Develop Regional Frequency Curves that are evaluated against the methodology/scientific principles used.

Governing Equations for Return Period – Return Level

Recurrence Interval or Return Period is defined as: An annual maximum event has a return period (or recurrence interval) of T years if its magnitude is equalled or exceeded once, on the average, every T years. The reciprocal of T is the exceedance probability, 1- F, of the event, that is, the probability that the event is equalled or exceeded in any one year (Bedient, 2002).

The probability (P) that an event (F) will occur in any year (T) is expressed mathematically as:

$$P(F) = \frac{1}{T}$$

Return Period is the reciprocal of probability and is expressed mathematically as:

$$T = \frac{1}{P}$$

Recurrences intervals (return periods) usually calculated are: 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years (annual-exceedance probabilities of 0.6667, 0.50, 0.4292, 0.20, 0.10, 0.04, 0.02, 0.01, 0.005, and 0.002, respectively). General equation for estimating the return level is in terms of the frequency factor for hydrological studies is given by Chow, 1964. The frequency factor depends on the type of distribution. It is expressed mathematically as:

$$y = \bar{y} + \sigma K$$

Index Method

The Index method was developed by Dalrymple in 1960. A summary of this method as given in the U.S Geological survey is given below.

Initially, single hydrometric station analysis is carried out and the corresponding frequency is developed. The variable used for single station analysis is the maximum instantaneous peak flow of the annual series. Then single station frequency curves are combined to give the regional frequency curves. This is completed in two steps. The first step is the development of the dimensionless frequency curve which represents the ratio of the flood of any frequency to an index flood known as mean annual flood. The second step is the development of the relationship between mean annual floods to the drainage area of the basin.

The procedure for the development of the frequency curve for any location is: (a) find the mean annual flood corresponding to the drainage area of the watershed; (b) from the first curve select ratios of peak discharge to mean annual flood for the selected recurrence interval; (c) multiply these ratios by the mean annual flood and plot the resulting discharges of these ratios by the mean annual flood and plot the discharge of known frequency to define the frequency curve. The procedure is explained in the upcoming section.

The mean annual flood is used to make the dimensionless frequency curve. Mean annual flood (index flood) is defined as the flood having a recurrence interval of 2.33 years. The premise for using the mean annual flood as the index flood is as follows. The magnitude of the mean annual flood is affected by both physiographic and meteorological factors of the drainage basin. A method to account for the composite effect of these factors is determined by dividing the study region into homogeneous hydrologic regions and correlating it to the most significant factor, the drainage area.

The Index Method assumes that the flow is natural, or with minimum regulation, and the region is homogeneous. There is no limit to the drainage area of the homogeneous region. The recurrence intervals are computed with a minimum of 10 years of record.

The Index method is popular as it is simple and most importantly, it requires only the drainage area of the watershed, making it suitable for watersheds where physio-meteriological data are sparse. The Index method was first introduced for flood flows and then later applied for low flows. The scientific principles remain the same for both flood and low flows.

Multiple Regression Method

Multiple linear regression is a multivariate statistical technique for examining the linear correlations between two or more independent variables (IVs) and a single dependent variable (DV). Multiple linear regression models are useful for:

- predicting unobserved values of the response (y(x) for new x)
- understanding which terms $a_i(x)$ have greatest effect on the response (coefficients a_i with greatest magnitude)
- finding the direction of the effects (signs of the ai)
- to what extent do x1, x2, and x3 (IVs) predict y (DV).

$$Y = a_0 + \sum_{i=1}^{p} a_i(X_i)$$

Here, the first use is being implemented. The governing equation is of the form:

where:

y = dependent variable (T-year flood flow – actual or transformed)

a_0 = regression constant

a_i = regression coefficient (s)

x_i = independent variable (s) (basin parameter – actual or transformed)

p = no. of independent variables used

The assumption of the analysis is that the residuals are normally distributed and have a straight line relationship with predicted DV scores, and the variance of the residual about the predicted scores is the same for all predicted scores.

Flood Flow Model

In 1978, the Government of Canada and the Province of Ontario entered into "An Agreement Respecting Flood Risk Mapping and Other Flood Damage Reduction Measures". The Index Method with Expected Probability Adjustment (Moin & Shaw, 1985) and the Secondary Multiple Regression Method (Moin & Shaw, 1985) commissioned by the Steering Committee are implemented here.

The flood flow model "Index Flood Method With Expected Probability Adjustment (Moin & Shaw 1985)" has estimated parameters of: Q1.25, Q2, Q5, Q10, Q20, Q50, Q100, Q200, Q500.

The flood flow model "Secondary Multiple Regression Method (Moin & Shaw 1985)" has estimated parameteres of: Q2, Q5, Q10, Q20, Q50, Q100.

Index Flood Method (Moin & Shaw 1985)

For the study, the province was divided into 12 regions based on the study conducted by Sangal and Kallio (1977) and a homogeneity test was conducted. The regions are shown in Figure 12. The variable used for single station analysis is annual peak instantaneous flow. Where this value is not available, the analysis uses the hydrograph method described by Sangal, 1981.

A total of 247 hydrometric stations with a record length of 10 or more years were used for the study. These stations have either natural or minimal regulation in flow. The data was fitted to the Three Parameter Log Normal Distribution. Split sample testing (Jack-Knife method) was done to validate the model. Eleven hydrometric stations from the total were kept aside. These stations were not used in developing the regional curve or in establishing drainage area versus mean annual flood relationships. The testing stations were treated as ungauged and the results of the single station analysis of these stations were compared with the regional model. The percentage error was tabulated and it is seen that Index Flood method gave predicted values which were quite reasonable except for two stations when compared to those obtained by the single station analysis.

The flow versus drainage area relationship is shown below. The equations coefficients and the corresponding drainage area range are given in Table 12. This method developed two equations:

- Drainage area greater or less than 60 square kilometres for region 1. This approach overcomes the limitation of the drainage area range to a certain extent.
- The dimensionless ratio of the regional frequency curves for each region is given in Table 13.

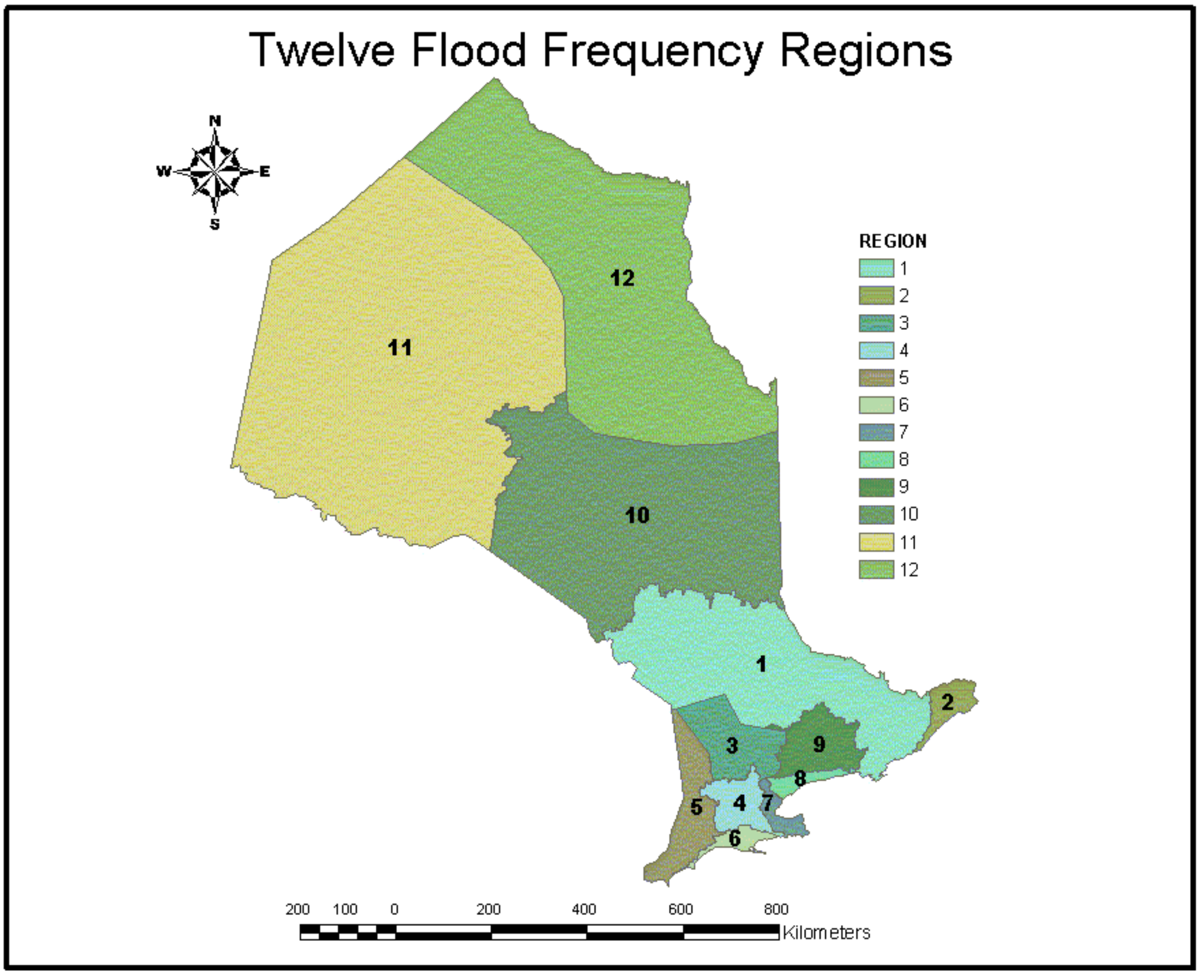

Figure 10: Twelve Flood Regions of Index Flood Method (Moin & Shaw, 1985).

General form of equation: $Q_2 = CA^n$ where:

Q_2 = 2 year return period (3PLN) flood

A = Drainage Area

C = Constant

n = exponent (slope)

Table 12: Coefficients of the Regression Equations

Region	Constant C	Exponent n
1(a)	0.22 (A < 60 km2)	1.000
1(b)	0.73 (A >60 km2)	0.707
2	0.51	0.896
3	0.20	0.957
4	0.71	0.842
5	0.45	0.775
6	0.41	0.806
7	1.13	0.696
8	0.73	0.785
9	0.40	0.81
10	0.28	0.849
11	0.38	0.706
12	0.59	0.765

Table 13: Range of Drainage Area Values for the Regression Equations

Region	Minimum (km2)	Maximum (km2)
1	0.11	9270
2	76.1	3816
3	86.0	3960
4	2.5	5910
5	14.2	4300

Region	Minimum (km2)	Maximum (km2)
6	5.2	697
7	63.5	293
8	4.9	800
9	24.3	1520
10	18.6	11900
11	0.7	24200
12	4250	94300

Table 14: Ratio of the Frequency Values

Region	Q1.25/ Q2	Q2/ Q2	Q5/ Q2	Q10/ Q2	Q20/ Q2	Q50/ Q2	Q100/ Q2	Q200/ Q2	Q500/ Q2
1	0.95	1.00	1.24	1.43	1.62	1.86	2.04	2.23	2.48
2	0.94	1.00	1.29	1.52	1.74	2.04	2.25	2.45	2.72
3	0.93	1.00	1.33	1.62	1.89	2.25	2.54	2.82	3.19
4	0.93	1.00	1.32	1.57	1.80	2.13	2.37	2.60	2.92
5	0.94	1.00	1.27	1.50	1.74	2.06	2.34	2.62	2.96
6	0.91	1.00	1.43	1.78	2.13	2.60	2.96	3.33	3.84
7	0.94	1.00	1.27	1.47	1.66	1.90	2.07	2.24	2.47
8	0.92	1.00	1.43	1.85	2.30	2.96	3.46	4.00	4.77
9	0.94	1.00	1.27	1.50	1.72	2.02	2.26	2.49	2.80
10	0.95	1.00	1.20	1.35	1.48	1.64	1.77	1.90	2.07
11	0.93	1.00	1.33	1.62	1.90	2.32	2.67	3.05	3.55
12	0.94	1.00	1.22	1.38	1.52	1.68	1.80	1.90	2.05

Another feature of this study was the introduction of the expected probability concept. The expected probability is defined as the average of the true probabilities of all magnitude estimates for any specified flood frequency that might be made from successive samples of specified size. It incorporates the effects of uncertainty in application of the curve. The Province of Ontario has adopted the policy where all frequency curves will be adjusted for the expected probability computations.

The average record length is employed to adjust the probabilities for each of the regions. N represents the number of years of record.

Table 15: Expected probability

Exceedance Probability	Expected Probability
0.005	0.005(1+52/N1.16)
0.01	0.01(1+26/ N1.16)
0.05	0.05(1+6/ N1.04)
0.1	0.1(1+3/ N1.04)
0.3	0.3(1+0.46/N0.925)

Multiple Regression Method (Moin & Shaw 1985)

The Multiple Regression Method was also included for the flood mapping studies along with the Index Method. As in the Index Method, the variable used for single station analysis is annual peak instantaneous flow. Where this value is not available, the analysis uses the hydrograph method described by Sangal, 1981. Gauging stations in Ontario were classified according to the degree of regulation. Regulated gauging stations are included in the 50 and 100 year return period with the premise that regulation has less impact on large events. Frequency curves were developed for gauging stations with more than 10 years of historic data. For 50 and 100 year return periods, 270 gauging stations were used, and for 2, 5, 10 and 20 year return periods, 217 gauging stations with natural flow or minor regulation were used.

The main feature of this method is the delineation of homogenous regions within Ontario using the standardized residuals from the 100 year return level. Three homogenous regions where found by grouping the residuals of similar magnitude and sign. These regions are shown in Figure 11.

Regression equations were developed for each of the three homogeneous regions. The parameters significant in the regression equations in the order of importance are: Drainage Area, Base Flow Index, Slope of the Main Channel, Area Controlled by Lakes and Swamps, Mean Annual Runoff, Mean Annual Precipitation, and Shape Factor.

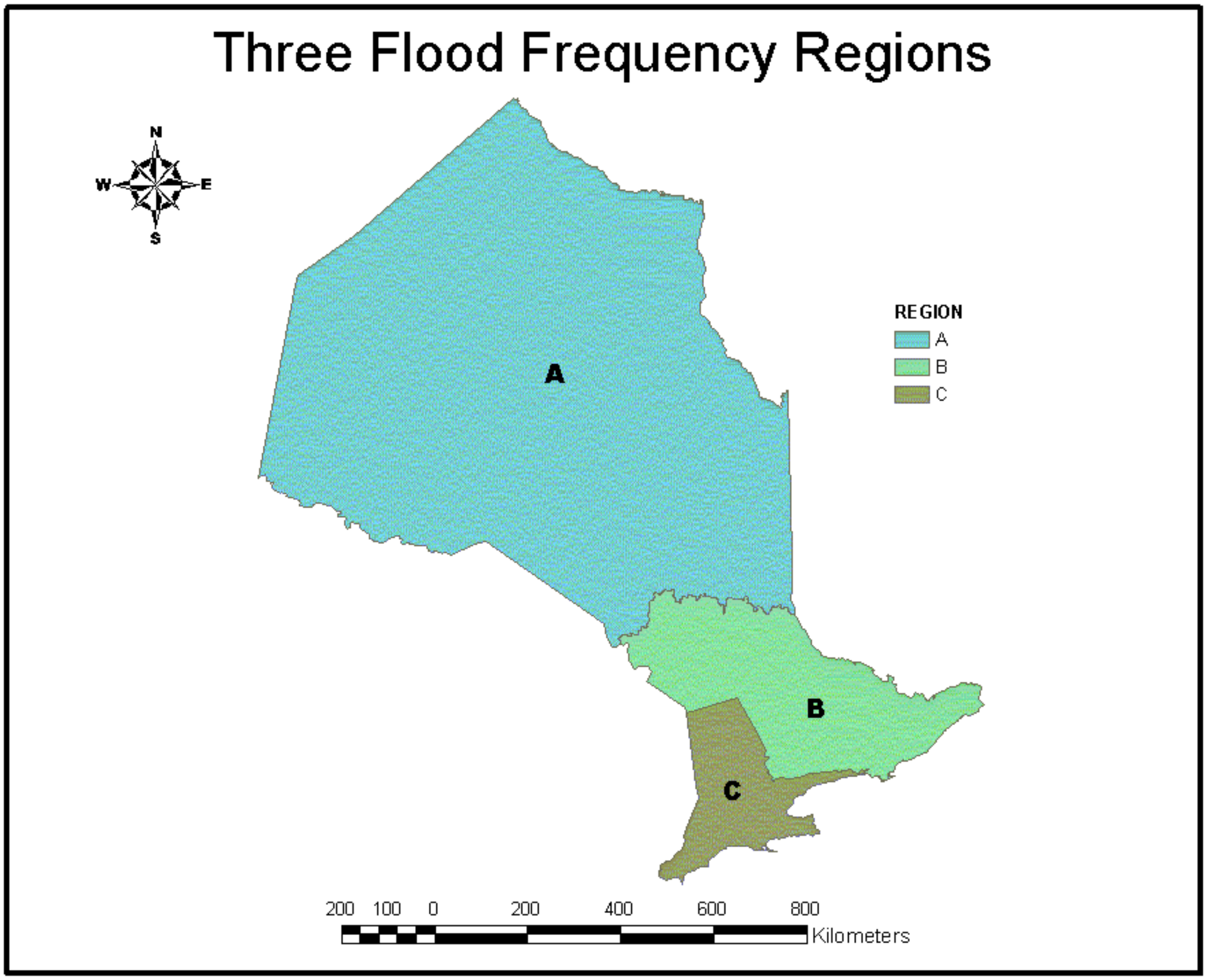

Figure 11: Three Flood Frequency Regions

Regression equations developed were tested on: measure of performance as expressed as percentage in difference from the single gauge analysis, sensitivity analysis of dependent variables, regression analysis, R2 of the equation, error analysis (same as Index method) and testing of regression equations with two stations each from each region. The test results indicated good prediction of estimates with acceptable error.

The model is calibrated for all the independent variables of the regression equation. The governing equations and the information are given below in Table 16.

Table 16: Variables used in the Moin & Shaw (1985) Regression Equation

Variable	Symbol
Drainage Area (km2)	DA
Mean Channel Slope (m/km)	SLP
Index of Area Controlled by Water & Wetland (%)	ACLS
Shape Factor (dimensionless) (=LNTH2/DA, where LNTH = length of main channel (km) and DA = drainage area (km2))	SF
Base Flow Index (dimensionless)	BFI
Mean annual Runoff (mm)	MAR
Mean Annual Precipitation (mm)	MAP

The regression equation is:

$\mathrm{Log(QT)} = a_0 + a_1\mathrm{Log(DA)} + a_2\mathrm{(BFI)}1/2 + a_3\mathrm{(SLP)}1/3 + a_4\mathrm{(ACLS)}1/2 + a_5\mathrm{(SLP)} +$
$a_6\mathrm{Log(MAR)} + a_7\mathrm{(MAR)} + a_8\mathrm{Log(ACLS+1)} + a_9\mathrm{(MAP)} + a_{10}\mathrm{(SF)}$

Regression co-efficients of the Multiple Regression Equations are listed below in the series of Tables.

Table 17: All Ontario, regression co-efficients.

Flow m3/sec	a0	a1	a3	a4	a7	SE	R2
Q2	-1.5689	0.8509	0.1635	-0.0339	0.0013	0.22	0.95
Q5	-1.3629	0.8370	0.2023	-0.0341	0.0012	0.21	0.85
Q10	-1.2251	0.8261	0.2154	-0.0341	0.0012	0.21	0.84
Q20	-1.1478	0.8205	0.2353	-0.0333	0.0012	0.21	0.84
Q50	-0.8744	0.8006	0.2315	-0.0359	9.7E-4	0.21	0.84
Q100	-0.7947	0.7950	0.2424	-0.0357	9.3E-4	0.22	0.83

Table 18: Region A, regression co-efficients.

Flow m3/ sec	a0	a1	a2	a7	a8	a9	SE	R2
Q2	0.5473	0.9418	-2.3038	0.0011	no data	no data	0.13	0.95
Q5	0.4916	0.8952	-1.7518	0.0012	-0.1007	no data	0.12	0.96
Q10	0.6927	0.8859	-1.8087	0.0010	-0.0907	no data	0.12	0.96
Q20	0.8670	0.8767	-1.8563	8.5E-4	-0.0819	no data	0.13	0.95
Q50	1.0335	0.9005	-2.3169	no data	no data	5.2E-4	0.13	0.94
Q100	1.0929	0.8889	-2.2764	no data	no data	5.1E-4	0.15	0.93

Table 19: Region B, regression co-efficients.

Flow m3/sec	a0	a1	a3	a4	a10	SE	R2
Q2	0.2143	0.7464	-0.2172	-0.0194	-0.0077	0.14	0.91
Q5	0.2746	0.7443	-0.1961	-0.0198	no data	0.14	0.89
Q10	0.3795	0.7217	-0.1799	-0.0202	no data	0.15	0.87
Q20	0.2311	0.7461	no data	-0.0197	-0.0081	0.15	0.87
Q50	0.3659	0.6989	no data	-0.0275	no data	0.15	0.85
Q100	0.4471	0.6839	no data	-0.0276	no data	0.16	0.83

Table 20: Region C regression co-efficients.

Flow m3/ sec	a0	a1	a3	a4	a5	a6	a8	SE	R2
Q2	-1.7155	0.8734	no data	-0.0167	no data	0.5580	no data	0.22	0.82
Q5	-1.7967	0.9031	0.1721	-0.0180	no data	0.5424	no data	0.21	0.83
Q10	-1.6547	0.8897	0.1841	-0.0177	no data	0.5261	no data	0.21	0.82
Q20	-1.5499	0.8786	0.1937	-0.0174	no data	0.5173	no data	0.22	0.81
Q50	-1.1793	0.8759	no data	no data	0.0337	0.4698	-0.0800	0.23	0.79
Q100	-1.1375	0.8676	no data	no data	0.0349	0.4804	-0.0811	0.23	0.78

The range of input values for the parameters of the Multiple Regression Equation are presented in the following tables.

Table 21: All Ontario multiple regression equation parameters.

Variable	**Q2-Q20 Minimum**	**Q2-Q20 Maximum**	**Q50-Q100 Minimum**	**Q50-Q100 Maximum**
DA	13.9	60100.0	13.9	395.5
BFI	0.15	1.0	0.15	0.56
SLP	0.02	9.42	0.02	1.22
ACLS	0.00	122.00	0.0	10.50
MAR	137.0	626.0	137.0	363.50
MAP	500.0	1000.0	500.0	840.0

Table 22: Region A multiple regression equation parameters.

Variable	**Q2-Q20 Minimum**	**Q2-Q20 Maximum**	**Q50-Q100 Minimum**	**Q50-Q100 Maximum**
DA	62.9	60100.0	62.9	118000.0
BFI	0.36	1.0	0.36	1.0
SLP	0.02	4.14	0.02	4.14
ACLS	0.0	100.0	0.0	100.0
MAR	193.0	598.0	193.0	598.00
MAP	N/A	N/A	500.0	1000.0

Table 23: Region B multiple regression equation parameters.

Variable	**Q2-Q20 Minimum**	**Q2-Q20 Maximum**	**Q50-Q100 Minimum**	**Q50-Q100 Maximum**
DA	13.9	3810.0	13.9	4770.0
BFI	0.26	0.82	0.26	0.90
SLP	0.14	5.77	0.02	5.77
ACLS	0.0	97.0	0.0	100.0
SHP	1.41	42.14	1.38	42.14

Table 24: Region C multiple regression equation parameters.

Variable	Q2-Q20 Minimum	Q2-Q20 Maximum	Q50-Q100 Minimum	Q50-Q100 Maximum
DA	14.2	5910.0	14.2	5910.0
BFI	0.15	0.81	0.15	0.81
SLP	0.21	9.42	0.21	9.42
ACLS	0.0	122.0	0.0	122.0
MAR	137.0	527.0	137.0	527.00

Low Flow Models

The Graphical Index Method (MOEE, 1995), and the Regression Method (MOEE 1995) implemented in OFAT were developed by Cumming Cockburn Limited for the Ontario Ministry of Environment and Energy.

The estimated output parameters from the Graphical Index Method (MOEE 1995) Low Flow model are: 1Q2, 1Q5, 1Q10, 1Q20, 1Q50, 1Q100, 3Q2 ,3Q5, 3Q10, 3Q20, 3Q50, 3Q100, 7Q2, 7Q5, 7Q10, 7Q20, 7Q50, 7Q100, 15Q2, 15Q5, 15Q10, 15Q20, 15Q50, 15Q100, 30Q2, 30Q5, 30Q10, 30Q20, 30Q50, 30Q100.

The estimated output parameters from the Regression Method (MOEE 1995) Low Flow model are: 3Q2, 3Q20, 3Q50, 7Q2, 7Q20, 7Q50, 30Q2, 30Q20, 30Q50.

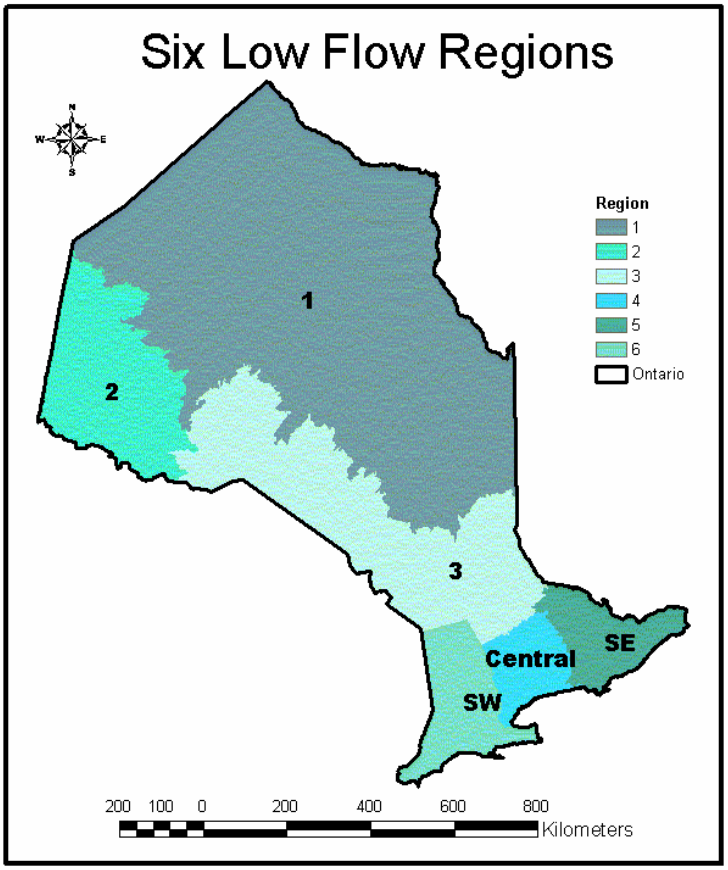

Figure 12: Six Low Flow Regions

As all methods were undertaken by the same consultant; the methodology for the single gauge station analysis and the generation of homogeneous regions remains the same. A total of 344 stations with more than 10 years of record were used for the study. Variables are extracted in two steps. First the moving average low flows (n-day) were determined, and then from that extreme low values are extracted for each year of the available data base. For the Index method, for each (n-day) 1, 3, 7, 15 and 30 duration frequency curves were developed for each station. For the regression method, only 7 day duration is used. The data is fitted to the Weibull Distribution, and then frequency curves of these stations were developed. The Province was divided into six hydrological homogeneous regions by grouping similar meteorological and physiographic characteristics. These homogeneous regions are depicted in Figure 12.

Index Method (MOEE, 1995)

Equations that relate the frequency with the drainage area, the calibrated values (range) of drainage area are given in Table 25. Application of the Index method resulted in a Nash-Sutcliff coefficient of 0.92 and 0.87 for 7Q2 and 7Q20 respectively.

General form of the equation: Q2 = CA, where:

Q2 = 2 year return period (3PLN) flood

A = Drainage Area

C = Constant n = exponent

Table 25: Regression equations of the Index Flood Method, 7Q2.

Region	Equation
1	7Q2 = 8.681 + 0.00208 * DA
2	7Q2 = -2.494 + 0.00325 * DA
3	7Q2 = -1.341 +0.00353 * DA
Central	7Q2 = 0.383 +0.00161 * DA
Southeastern	7Q2 = -1.60 +0.00251 * DA
Combined Central and Southeastern	7Q2 = 0.118 + 0.00205 * DA

Regression Method (MOEE, 1995)

Watershed characteristics, Drainage Area, Length of Main Channel, Mean Annual Runoff, Base Flow Index and Mean Annual Snowfall were used to make the regression equations. This method also develops two equations for the regions 1, 2 and 3 for drainage areas greater or less than 17,000 km2. This approach overcomes the limitation of the drainage area range. The equations for each region, their coefficients and the calibrated watershed values are given in the following tables.

Sensitivity analysis of the watershed parameters show that the drainage area to be the most sensitive. Nash- Sutcliff coefficient of 0.68 and 0.86 were obtained for 7 day, 2 and 20 year recurrence intervals.

Northeastern and Northwestern Regions

Table 26: Regression equation variables for NE and NW regions.

Variables	Symbol
Drainage Area (km2)	DA
Length of Main Channel (km)	LNTH
Mean Annual Runoff (mm)	MAR

The general form of multiple regression equation for 7Q2 and 7Q20 is:

$$Y = a_0 + a_1 (DA) + a_2 (DA)^{1/2} + a_3 (DA)^2 + a_4 (LNTH) + a_5 (LNTH)^{1/2} + a_6 (MAR) + a_7 (MAR)^2$$

Table 27: Coefficients of multiple regression equations for 7Q2.

Region	a0	a1	a2	a3	a4	a5	a6	a7
1	-35.766	no data	0.8628	no data	no data	-4.130	no data	0.000353
2	21.65	0.00337	no data	no data	no data	-4.791	0.18088	no data
3	7.506	no data	no data	1.581*10-7	no data	0.5491	-0.0156	no data
1, 2, and 3, DA < 17000 km2	-3.15	0.00323	no data	no data	0.01898	no data	0.00756	no data

Table 28: Coefficients of multiple regression equations for 7Q20.

Region	a0	a1	a2	a3	a4	a5	a6	a7
1	-25.718	no data	0.5587	no data	no data	-2.89	no data	0.000272
2	8.124	0.00125	no data	no data	no data	-0.796	-0.0104	no data
3	0.4185	no data	no data	9.777*10-8	no data	0.3403	-0.0055	no data
1, 2 and 3, DA < 17000 km2	-2.45	0.0016	no data	no data	-0.0021	no data	0.0047	no data

Central and Southeastern Regions

Table 29: Regression equation variables used in Central and SE regions.

Variables	Symbol
Drainage Area (km2)	DA
Base Flow Index (dimensionless)	BFI

The general form of multiple regression equation : $Y= a_0 + a_1(DA) + a_2(BFI)$

Table 30: Multiple regression equation coefficients for central region.

Flow (m3/sec)	a0	a1	a2
7Q20	-0.2134	0.00066184	0.7022
7Q2	-0.7216	0.0018060	1.7386
3Q2	-0.5398	0.0016260	1.2856
3Q20	-0.1841	0.00058893	0.6295
3Q50	-0.1331	0.00045199	0.5160
30Q2	-0.7119	0.0022380	1.6806
30Q20	-0.3275	0.00097749	0.9305
30Q50	-0.2839	0.00087086	0.8045

Table 31: Multiple regression equation coefficients for southeastern region.

Flow (m3/sec)	a0	a1	a2
7Q20	-0.5084	7.6323E-11	1.1460
7Q2	-0.9018	1.3049E-10	2.2728
3Q2	-1.0351	1.2409E-10	2.3828
3Q20	-0.6133	7.0980E-11	1.2527
3Q50	-0.6226	6.5153E-11	1.2372
30Q2	-1.0195	1.4637E-10	2.6144
30Q20	-0.5196	8.5495E-11	1.3062
30Q50	-0.4643	7.9836E-11	1.1773

Southwestern and West Central Regions

Table 32: Regression equation variables used in WC and SW regions.

Variables	Symbol
Drainage Area (km2)	DA
Base Flow Index (dimensionless)	BFI
Length of Main Channel (km)	LNTH
Mean Annual Runoff (mm)	MAR
Mean Annual Snow (cm)	MAS

The general form of multiple regression equation for the Southwestern and West central Regions:

$$Y= a_0 +a_1 (DA)^3 +a_2 (BFI)^2 +a_3 (LNTH)^2$$

Table 33: Multiple regression equation coefficients for WC and SW region.

Flow m3/sec	a0	a1	a2	a3
7Q2	-0.190	1.24E-10	1.67	8.35E-5
7Q20	-0.166	9.03E-11	1.10	4.67E-5
7Q50	-0.160	8.54E-11	1.02	3.92E-5
3Q2	-0.183	1.21E-10	1.55	7.81E-5
3Q20	-0.158	8.57E-11	0.99	4.30E-5
3Q50	-0.150	7.92E-11	0.91	3.64E-5
30Q2	-0.233	1.29E-10	2.12	1.12E-4
30Q20	-0.227	9.58E-11	1.52	no data
30Q50	-0.078	1.25E-10	1.44	no data

Each low flow region uses a different range of hydrologic parameters to develop models, limiting their use. Ranges of input parameters for each region are shown in the following tables.

Table 34: Region 1 range of input parameters.

Variable	MAP	MAS	MAR	EVA	DA	BFI	LNTH	ACLS
Min	500	190	108	340	401	0	25	0
Max	830	305	456	450	94300	1	476.3	100

Table 35: Region 2 range of input parameters.

Variable	MAP	MAS	MAR	EVA	DA	BFI	LNTH	ACLS
Min	695	190	154	490	744	0.68	4	0
Max	790	230	406	515	50200	0.99	238.1	100

Table 36: Region 3 range of input parameters.

Variable	MAP	MAS	MAR	EVA	DA	BFI	LNTH	ACLS
Min	695	190	154	490	744	0.68	4	0
Max	790	230	406	515	50200	0.99	238.1	100

Table 37: Region 4 (Central) range of input parameters.

Variable	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS
Min	780	120	189	0.02	665	24.3	0.17	9	0
Max	1000	300	527	9.434	830	1520	0.82	94.3	100

Table 38: Region 5 (Southeastern) range of input parameters.

Variable	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS
Min	800	170	260	0.14	635	7	0.3	5	0
Max	920	200	540	12.19	790	4120	0.88	112.4	100

Table 39: Region 6 (Southwestern) range of input parameters.

Variable	MAP	MAS	MAR	SLP	EVA	DA	BFI	LNTH	ACLS
Min	780	90	137	0.00034	14.2	0.1	6.1	1	1
Max	1020	350	516	0.00747	3960	0.8	190.5	100	100

Mean Annual Flow (MAF) Model

Currently, OFAT contains the Isoline Method (Environment Canada, 1986) to estimate mean annual flow (cms). The original provincial isoline map for mean annual runoff (mm) was first digitized and then a continuous surface (a map) with 1km * 1km cell resolution was created from the isolines. The mean annual runoff (mm) for the watershed is calculated by averaging all the cell values within the watershed boundary, which can be converted into mean annual flow (cms).

Appendix 2: Provincial Application Areas of OFAT

Permit To Take Water (2007)

Sections 34: Ontario Water Resources Act, R.S.O. 1990 and Water Taking Regulation O. Reg. 387/04

Permit to Take Water Guideline recommendation for Surface Water Taking of Category 2 is “River and Streams (3rd order or higher order) takings less than 5% of 7Q20.”

Approval of Sewage Works (2010)

Sections 53: Ontario Water Resources Act R.S.O. 1990

a. Industrial Sewage Works

Under the Environmental Impact Analysis of Surface Water Impact states the limiting conditions as “Limiting conditions within the receiving water body, including: Low flow conditions in the receiving water body, e.g., the 7Q20 for a stream, i.e., the 7-day average low flow occurring once in 20 years”.

b. Municipal and Private Sewage Works

Under the Environmental Impact Analysis of Surface Water Impact states the limiting conditions as “Limiting conditions within the receiving water body, including: Low flow conditions in the receiving water body, e.g., the 7Q20 for a stream, i.e., the 7-day average low flow occurring once in 20 years”.

Approval under the Lakes & Rivers Improvement Act (2010)

Sections 14 and 16: Lakes and Rivers Improvement Act (LRIA) 1927 and Ontario Regulation 454/96.

Flow recommendations as given in the technical guidelines are:

> “The design flow for fish passage should not exceed a frequency of a 1:10 year 3 day delay. This is the flow that is exceeded on average every ten years for three consecutive days”.

"The PMF (probable maximum flood) is not normally used for channel design. The channel capacity may be designed for less than the 25 year flood, e.g., 10, 5, or 2 year flood, but the combined capacity of the channel and flood plain must meet the design flood criteria for small dams in the table"

"Bankfull discharge of a river natural flow channel usually corresponds to the 1:2.33 year to the 1:5 year return period depending upon the stream type and basin conditions".

Table 40: Minimum design floods for road crossing.

Road Classification	**Total Span up to 6.0 metres**	**Total Span over 6.0 metres**
Freeways and Urban Arterial Roads	50 year	100 year or Regulatory Flood depending on local conditions
Rural Arterial and Collector Roads	25 year	50 year
Local (unpaved) Roads and Resource Access	10 year	25 year
Temporary Detours	1 to 5 year	1 to 10 year

Flooding Hazard Limit

Natural Hazard Policies of the Provincial Policy Statement of the Planning Act (2002).

River System Flood Standards:

Zone 1 the peak flow resulting from the Hurricane Hazel1 Storm or the 100 year flood, whichever is greater.

Zone 2 the 100 year flood.

Zone 3 the peak flow resulting from the Timmins2 Storm or the 100 year flood, whichever is greater; depending on the location in the province.

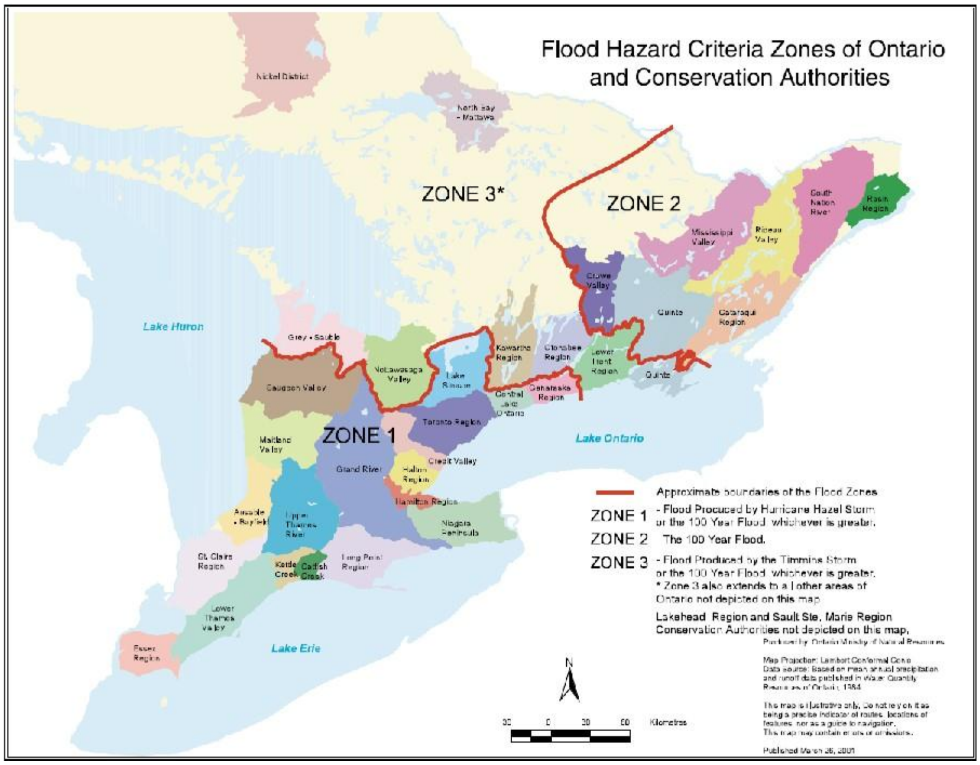

Figure 13: Flood hazard criteria zones.

Adaptive Management

Natural Channel System: Adaptive Management of Stream Corridors in Ontario

The full regime flows should be included:

> "Low flow - 7Q2, 7Q10, 7Q20 (biological requirements)
>
> Bankfull flow - 1:1.5 to 1:5 year event (geomorphology requirements)
>
> Riparian flow - 1:10 to 1:25 year event (biology, geomorphology)
>
> Valley flow/flood plain - 1:100 to Regional event"

Design Flood for River and Stream Crossing based on Risk

MTO Drainage Management Manual (1997)

Risk is usually expressed as a probability, P that a flood will be exceeded in any one-year period and can be expressed as: $P = 1 - (1 - 1/Tr)\ n$, where:

- Tr = return period of the storm in years
- n = life of the structure in years

Table 41: Percent probability of exceedance during life of structure.

Average Return Period Years	2.3 years	5 years	10 years	25 years	50 years	100 years
2.33	73	94	100	100	100	100
5	41	67	89	100	100	100
10	22	41	64	93	99	100
25	9	18	34	64	87	98
50	5	9	18	41	64	87
100	2	5	9	22	40	64
1000	0	1	1	3	5	10

Peak Flow Rate Criteria

Storm water management planning and design manual (2003)

"Generally, accepted criteria are that maximum peak flow rates must not exceed pre-development values for storms with return periods ranging from 2 to 100 years. Peak flow rates must be determined on a site by site basis. Existing rates can be determined utilizing computer simulation modelling or by transposing a frequency analysis of measured peak flow rates on a unit area basis to a site".

Ontario Low Water Response

Indicator thresholds for Low Water Conditions

Level I: Voluntary Conservation

- Precipitation is less than 80 % of average
- Spring: monthly streamflow is less than 100 % lowest average summer month flow
- Other times: monthly flow < 70 % of lowest average summer month flow

Level II: Conservation and Restrictions on Non-Essential Use

- Precipitation is less than 60% of average weeks with less than 7.6 mm
- Spring: monthly streamflow is less than 70% of lowest average summer month flow
- Other times: monthly streamflow is less than 50 % of lowest average summer month flow

Level III: Conservation, Restriction, Regulation

- Precipitation is less than 40% of average
- Spring: monthly streamflow is less than 50% of lowest average summer month flow
- Other times: monthly streamflow is less than 30% of lowest average summer month flow

"An indication of streamflow approaching the minimum needed to maintain the ecosystem is the statistical flow value, 7Q20", "Comparing the value of the current flow with the historic low value will determine when the streamflow is approaching the 7Q20".

"Streams in the headwaters or those having high width-to- depth ratio are expected to be more sensitive to low flows. An indication of streamflow approaching the minimum needed to maintain the ecosystem in these streams is the statistical flow value, 7Q2".

Water Budget

Section 15 (2) Clean Water Act (2006)

Water Budget and Water Quantity Risk Assessment Guide (2011)

"Water Budget Components:", "Analyse Streamflow (QSW). The analysis will include estimates of streamflow statistical parameters (i.e.QP90, QP50, Qavg) where continuous records exist, analysis of spot flow measurements or pro- rating of data from nearby gauges. The analysis may also include baseflow separation at gauged surface water stations."

"Surface Water Supply Estimation Methods:", "The 30Q2 flow provided by OFAT is an estimate of average annual baseflow (Pryce, 2004). This flow could be considered as

the water supply for each month, as the tools in OFAT cannot provide monthly low flow estimates. OFAT cannot account for flow augmentation and regulation controls. Therefore the team must understand its limitations in estimating baseflow.”

“Tier One Surface Water Monthly Water Reserve Estimation Methods:”, “When a continuous stream gauge is available, the surface water reserve may be calculated for each month as the monthly lower decile flow (QP90), or the flow that is exceeded 90% of the time for each month.”

“Surface Water Stress Assessment:”, “Surface water reserve is calculated as the monthly lower decile flow (Q90) at the outlet of the subwatershed for Tier Two. The water reserve estimate may be the same in Tier One where a reliable surface water gauge is located at the outlet of the subwatershed.”

“Significant Risk Circumstances – Groundwater:”, “Under scenario G (existing plus committed plus planned demand), the municipal takings result in measurable and unacceptable impacts to other uses. For coldwater streams, an unacceptable impact is defined by a circumstance where groundwater discharge is reduced by more than 20% as compared to the existing estimated monthly streamflow Qp80 (the flow that is exceeded 80 percent of the time) or the average monthly baseflow of the watercourse or another threshold that has already been defined as a condition in an existing permit. In situations where another threshold has been defined, that threshold would be used to identify a significant risk.”

Climate Change

Guide for Assessment of Hydrologic Effects of Climate Change in Ontario, 2010

“Summary of hydrologic change metrics”, “Mean Flows: Mean annual flow, Mean monthly flows, Mean seasonal flow”, “Peak Flow Statistics: Recurrence Interval peak flows (e.g., 2-Year, 100-Year)”, “Flow Distribution: Flow frequency- duration curve”, “Low Flow Statistics: 1Q10 , 7Q10 , 7Q20.”

“After selecting the hydrologic metrics, the study team must decide how to compare the climate change impacts to the reference regime. The following methods can be used to compare the estimated impacts with each metric: Absolute Change. Estimate the absolute change in the hydrologic metric (e.g., 7Q10 decreases from 10 L/s to 7 L/s). Relative Change. Estimate the percent change in the hydrologic metric (e.g., 7Q10 decreases 30%). Frequency Change. Estimate the change in the frequency of exceedance for a metric (e.g., frequency of overbank flow increases from 2.5 times per year to 2.8 times per year).”

Other Areas Indirectly Connected to Streamflow

“Average Annual Water Yield: the amount of freshwater derived from unregulated flow (m3 s-1) measurements for a given geographic area over a defined period of time. Used to estimate stocks of water assets for the Water Accounts component of Statistics Canada’s environmental accounting framework, the Canadian System of Environmental and Resource Accounts”

“Yearly runoff surfaces were then averaged to produce the thirty-year surface and scaled back to a volume based on the resolution (100 km2) of the surfaces, producing the water yield estimate.”

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The Ontario Ministry of Natural Resources and Ministry of the Environment in partnership with Credit Valley Conservation. Guide for Assessment of Hydrologic Effects of Climate Change in Ontario, 2010. (http://www.waterbudget.ca/climatechangeguide)

Appendix 3: Other References

IDF Curves

An Intensity-Duration-Frequency curve (IDF curve) is a graphical representation of the probability that a given average rainfall intensity will occur. It characterizes the rainfall pattern of the area. Usually 2, 5, 10, 25, 50 and 100 year return periods are shown on IDF curves.

Rainfall Intensities for the province of Ontario can be found in:

MTO-IDF Curve Lookup (http://www.mto.gov.on.ca/IDF_Curves/)

Duration: 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hr, 2 hr, 6 hr, 12 hr, 24 hr

Recurrence Interval: 2, 5, 10, 25, 50, 100 years

Environment Canada, National Climate Data Archive

Free download FTP site; **ftp://arcdm20.tor.ec.gc.ca/pub/dist/IDF/**

Duration: 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hr, 2 hr, 6 hr, 12 hr, 24 hr

Recurrence Interval: 2, 5, 10, 25, 50, 100 years

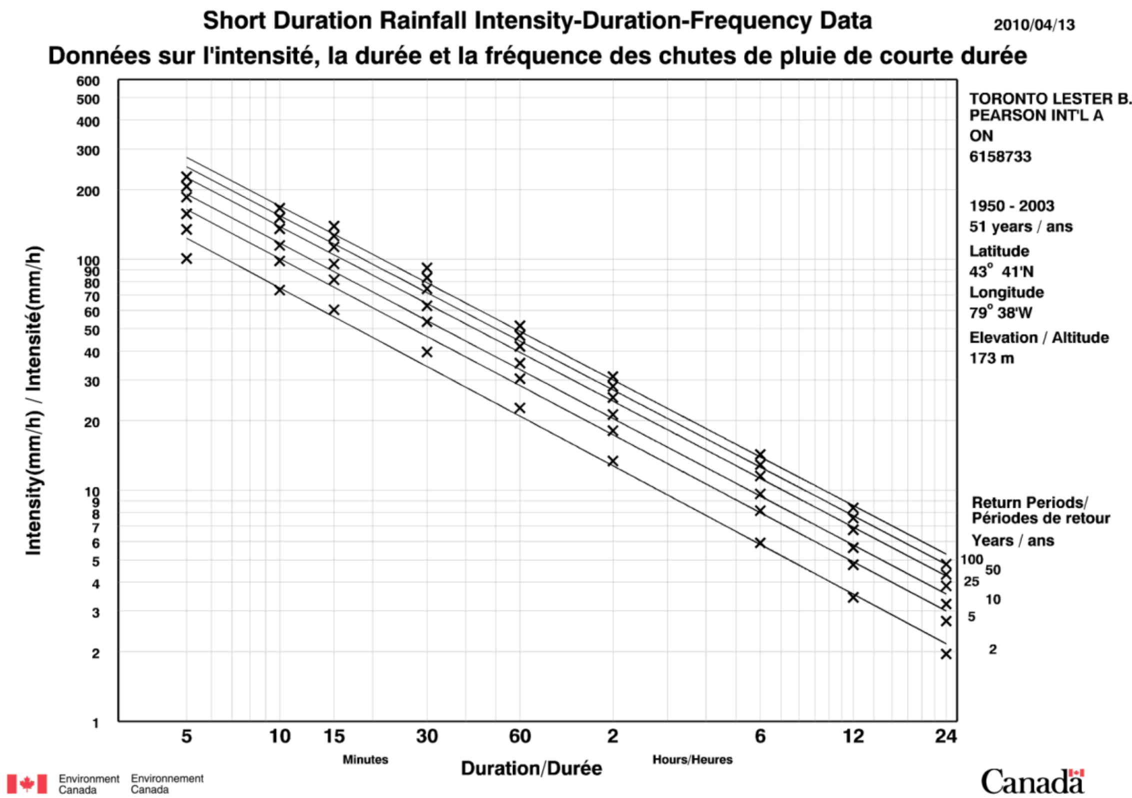

Figure 14: IDF Curve of Toronto Lester B Pearson International.